ACRP
Research Report 234

Airport Cooperative Research Program
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Rapid Slab Repair and Replacement of Airfield Concrete Pavement

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP RESEARCH REPORT 234

Rapid Slab Repair and Replacement of Airfield Concrete Pavement

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). ACRP carries out applied research on problems that are shared by airport operating agencies and not being adequately addressed by existing federal research programs. ACRP is modeled after the successful National Cooperative Highway Research Program (NCHRP) and Transit Cooperative Research Program (TCRP). ACRP undertakes research and other technical activities in various airport subject areas, including design, construction, legal, maintenance, operations, safety, policy, planning, human resources, and administration. ACRP provides a forum where airport operators can cooperatively address common operational problems.

ACRP was authorized in December 2003 as part of the Vision 100—Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academy of Sciences formally initiating the program.

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ACRP PROJECT 09-18 PANEL
Field of Maintenance

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Individuals with the following organizations completed an online survey that provided a general understanding of industry trends in current rapid slab repair and replacement (RSRR) practices:

- Airport International Group,
- Airports Authority of India,
- Chandler Municipal Airport,
- City of San Antonio Aviation Department,
- Columbus Regional Airport Authority,
- Denver International Airport,
- Duluth International Airport,
- Golden Triangle Regional Airport,
- Hatch Corporation,
- Cincinnati/Northern Kentucky International Airport,
- Los Angeles World Airports,

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- McFarland Johnson, Inc.,
- Michael Baker International,
- National University of Singapore,
- Ogden–Hinckley Airport,
- Phoenix Sky Harbor International Airport,
- Port Authority of New York and New Jersey,
- Salt Lake City International Airport,
- Seattle–Tacoma International Airport,
- T-O Engineers, and
- Venango Regional Airport.

Individuals at the following airport agencies (and/or their engineering consultants) participated in case example interviews or accommodated field visits during construction projects, which allowed documentation of RSRR practices:

- Cincinnati/Northern Kentucky International Airport (C&S Engineers),
- Gerald R. Ford International Airport (C&S Engineers),
- Hartsfield–Jackson Atlanta International Airport (Michael Baker International),
- John Glenn Columbus International Airport,
- Los Angeles International Airport,
- Louisville Muhammad Ali International Airport (HNTB Corporation),
- McCarran International Airport,
- Phoenix Sky Harbor International Airport,
- Raleigh–Durham International Airport [Jacobs Engineering Group Inc (CH2M)],
- San Francisco International Airport,
- Seattle–Tacoma International Airport, and
- Vancouver International Airport (Hatch Corporation and Associated Engineering).

FOREWORD

By Marci A. Greenberger
Staff Officer
Transportation Research Board

Whether in a commercial service or general aviation airport, the closure of a critical pavement asset has a significant impact on operations, especially if that asset is the runway at a single-runway airport. *ACRP Research Report 234: Rapid Slab Repair and Replacement of Airfield Concrete Pavement* will assist airport personnel in planning, designing, and constructing appropriate rapid slab repair and replacement (RSRR) activities to cost-effectively minimize the impact of pavement-related closures. Airports can benefit from guidance on these activities, since their execution can differ from traditional pavement repair and replacement.

The cost and inconvenience of closing critical airfield pavement for repair can be significant. Airports want to minimize closures for repair and rehabilitation projects and, therefore, are increasing the use of rapid repair and replacement of airfield concrete pavement slabs. This report provides updated guidance based on recent advancements in materials and procedures for rapid repair of airfield concrete pavement.

A team led by Nichols Consulting Engineers, Chtd., was selected to develop guidance to help airports determine whether RSRR activities are appropriate for replacement and rehabilitation of concrete slabs and guide them through the planning, design, and construction phases. The developed guidance is based on surveys, interviews, and site visits at airports engaged in RSRR activities and complements information provided in FAA Advisory Circular 150/5370-16, *Rapid Construction of Rigid (Portland Cement Concrete) Airfield Pavements*.

This guidance will be useful to airport engineering and maintenance staff and engineering consultants at airports of all sizes and will help them select and execute appropriate RSRR activities.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Rapid Slab Repair and Replacement of Airfield Concrete Pavement

Proper maintenance and repair of concrete airfield pavements are critical to their longevity and ability to safely support airport operations over their design life. However, these activities can be costly and operationally disruptive, as they require closure of the pavement facility. To minimize the construction impacts, airports of all sizes are relying on rapid slab repair and replacement (RSRR) activities that include partial- and full-depth repairs (both partial- and full-slab replacements). Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5370-16, *Rapid Construction of Rigid (Portland Cement Concrete) Airfield Pavements* (FAA 2007), addresses many key components and considerations for accelerated concrete construction but stops short of providing sufficient details or specific methods to aid airport personnel or consulting engineers in making informed decisions. Furthermore, AC 150/5370-16 focuses on larger areas of concrete replacement and provides only limited information on individual slab replacement or smaller repairs. In addition, FAA Item P-501, "Portland Cement Concrete Pavement" in *Standard Specifications for Construction of Airports* (AC 150/5370-10H) (FAA 2018), does not provide specifications for construction featuring early-strength concrete or prepackaged repair materials used in RSRR projects.

Major challenges to completing RSRR include stakeholder coordination, airfield closures, high construction costs, and lack of experience with early-strength concrete repair materials. While the necessary level of stakeholder coordination regarding airfield closures varies by airport size and function, high costs and lack of experience with these types of repairs are a universal challenge. Large hub airports have good experience with RSRR, and some have advanced programs in place. Importantly, elements of their RSRR programs and practices are easily applied by smaller airports (e.g., nonhub primary and general aviation) that are less likely to have RSRR experience.

This guidebook was developed to assist airport personnel and engineering consultants in selecting and executing RSRR projects, and it provides relevant information for airport maintenance personnel performing RSRR work. It is based on a review of the literature, an online survey of airports, interviews with airport personnel and engineering consultants with RSRR experience, and site visits to observe and document important aspects of RSRR construction. Furthermore, this guidebook covers the overall RSRR process, including planning, design, and construction. It builds on information provided in FAA AC 150/5370-16 (FAA 2007) and other relevant documents considered to represent current state-of-the-practice for RSRR.

Ten case examples of RSRR practice and programs at airports across the country along with key takeaways from observing five RSRR construction projects are provided to illustrate the guidance provided herein. Key technical documents are cited throughout the guidebook to provide additional resources and technical information.

CHAPTER 1

Introduction

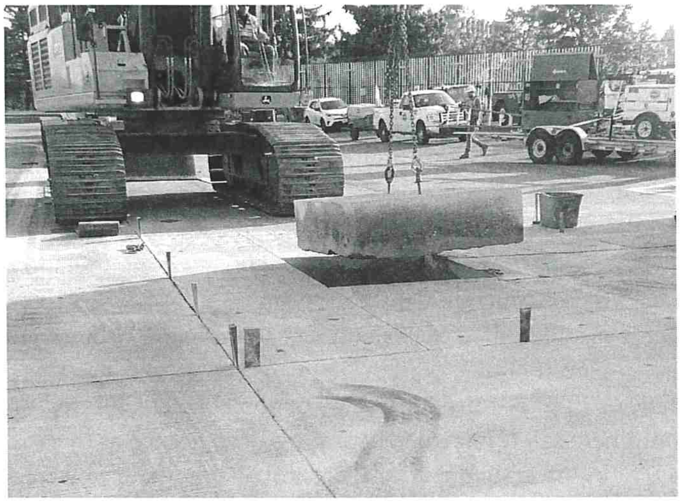
Background

Proper maintenance and repair of concrete airfield pavements is critical to the longevity of these pavements and their ability to safely support airport operations over their design life. However, these activities can be costly and operationally disruptive, as they require closure of the pavement facility. To minimize the cost to airline operators and passengers, multirunway airfields with spare capacity can shift traffic to other runways to permit required closures for these activities. Similarly, airports with multiple taxiways or large aprons can sometimes reroute traffic or temporarily shift aircraft parking, respectively. However, these alternatives can still result in delays. At smaller, single-runway airfields or those operating at or near capacity, shutting down a runway (or an entire taxiway/apron) for an extended period to conduct repairs is simply not an option. To minimize construction impacts, airports of all sizes rely on rapid slab repair and replacement (RSRR) activities (Figure 1) done on an accelerated construction time frame, often with overnight construction windows. In such circumstances, the planning and design phases become important components in delivering an accelerated product.

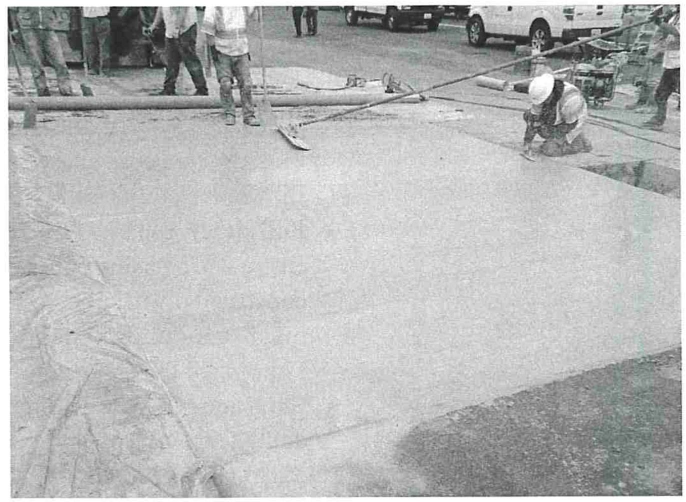
Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5370-16, *Rapid Construction of Rigid (Portland Cement Concrete) Airfield Pavements* (FAA 2007), addresses many key components and considerations for accelerated concrete construction but stops short of providing sufficient details or specific methods to aid airport personnel or consulting engineers in making informed decisions. Furthermore, AC 150/5370-16 focuses on larger areas of concrete replacement and provides only limited information on replacement of an individual slab or smaller repairs. In addition, FAA Item P-501, "Portland Cement Concrete Pavement" in *Standard Specifications for Construction of Airports* (AC 150/5370-10H) (FAA 2018), does not provide specifications for early-strength concrete (ESC)—also known as rapid-strength, rapid-set, or fast-track repair materials—needed for RSRR projects.

An online survey was conducted to determine current trends with RSRR. Twenty-one individuals responded to the survey, representing 10 large hub, three medium hub, one small hub, four nonhub primary, and three general aviation airports. The survey results indicated the following:

- These airports possess a wide range of experience, from planning to construction. Respondents that reported no previous RSRR experience represented either nonhub primary or general aviation airports.
- Stakeholder coordination and lack of skilled contractors and workforce are primary challenges. While the level of stakeholder coordination varies across airports (by size and function), the lack of skilled contractors and workforce is a universal challenge.
- Airport satisfaction with RSRR performance is mixed, with shorter-than-expected service life cited as the main reason for dissatisfaction.



(a)



(b)

Source: Nichols Consulting Engineers, Chtd.

Figure 1. Example of rapid slab replacement on an airfield: (a) slab removal (saw cut into pieces) and (b) concrete finishing.

The airport responses indicated that although RSRR projects are common, guidance would be welcomed to improve performance.

Purpose

The purpose of this guidebook is to assist airport personnel and engineering consultants in selecting and executing RSRR projects and to provide relevant information for airport maintenance personnel performing RSRR work. It covers the overall RSRR process (i.e., planning, procurement/project delivery, design, and construction) with detailed emphasis on construction considerations, materials, specifications, and practices that build on information provided in FAA AC 150/5370-16, *Rapid Construction of Rigid (Portland Cement Concrete) Airfield Pavements* (FAA 2007). This guidebook provides references to additional technical resources for ESC and patching materials needed for RSRR. The appendices provide case examples of RSRR programs at airports across the country along with key takeaways from RSRR construction projects that illustrate the guidance provided herein.

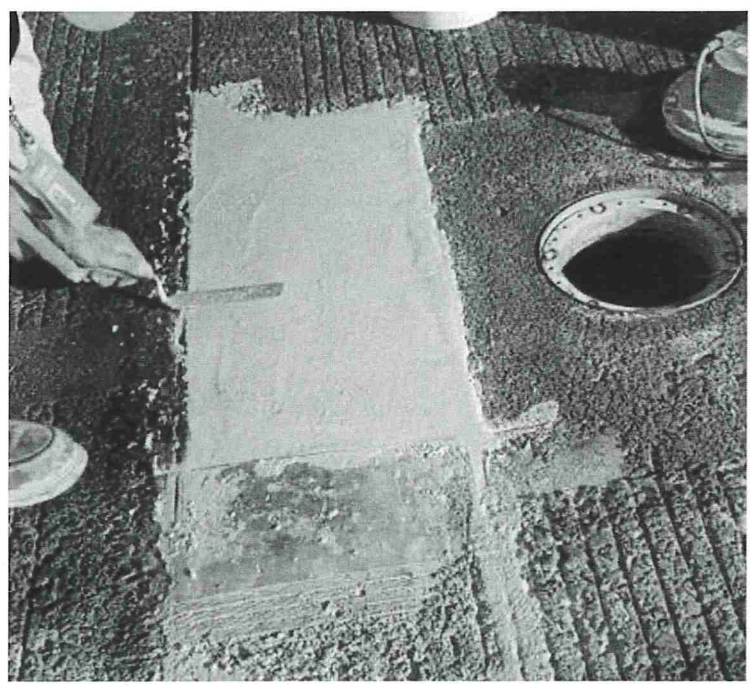
Key Definitions

The following terms are relevant to describing RSRR and are used throughout this report:

- **Rapid construction:** Construction conducted under an accelerated schedule because of high demand and/or limited alternate routes for aircraft operations. Work is generally done over a short construction window during specified hours (i.e., nighttime, off-peak hours, weekend). The following definitions of closure are used throughout this report:
  - **Overnight closure (<8 hours):** Intended for critical areas of airfield pavement that are repaired during a short closure window (e.g., a nighttime closure that must be reopened to aircraft traffic the following morning),
  - **Full-day closure (8–24 hours):** Intended for critical areas of pavement that have some flexibility in timing for opening to traffic, and
  - **Weekend closure (24–54 hours):** Intended for critical or noncritical areas of pavement that can be closed over an entire weekend.

- **Partial-depth repair (PDR):** Removal of small areas of damaged pavement limited to the upper half of the thickness of the concrete slab and replacement with a cementitious or polymeric repair material. PDR is a common practice for maintaining and preserving concrete pavements. When durable repair materials and proper construction techniques are selected, PDR can be a cost-effective, long-term solution for concrete airfield pavement needs. Figure 2 shows an example of PDR installation.
- **Full-depth repair (FDR):** Full-depth removal and replacement of a portion of a slab or an entire slab by using either cast-in-place concrete or precast concrete. FDRs are predominantly constructed with cast-in-place ESC. Precast concrete slabs have been used for slab replacement to a limited extent on airfields in the United States and Canada. Figure 3 shows an example of the more common cast-in-place FDR.
- **Emergency work:** Immediate PDR or FDR required to repair or replace deteriorated or damaged concrete that poses an imminent safety hazard to operating aircraft, such as by producing foreign object debris (FOD) or by affecting directional control of aircraft, or prevents use of the affected airfield pavement.
- **Nonemergency work:** PDR or FDR required for routine pavement maintenance or preservation. The distressed or deteriorated concrete pavement does not pose an imminent safety hazard to operating aircraft—that is, it does not produce FOD and does not affect directional control of aircraft—but may or may not prevent the use of the affected airfield pavement.
- **Early-strength concrete (ESC):** Concrete with early strength gain characteristics, also known as rapid-strength, rapid-set, or fast-track concrete. ESC can be categorized as follows:
  - **Very high-early-strength (VHES) concrete:** Concrete mixture with an opening-to-traffic time of 4 hours or less, typically produced with ASTM C1600 cements;
  - **High-early-strength (HES) concrete:** Concrete mixture with an opening-to-traffic time of 8 to 20 hours; and

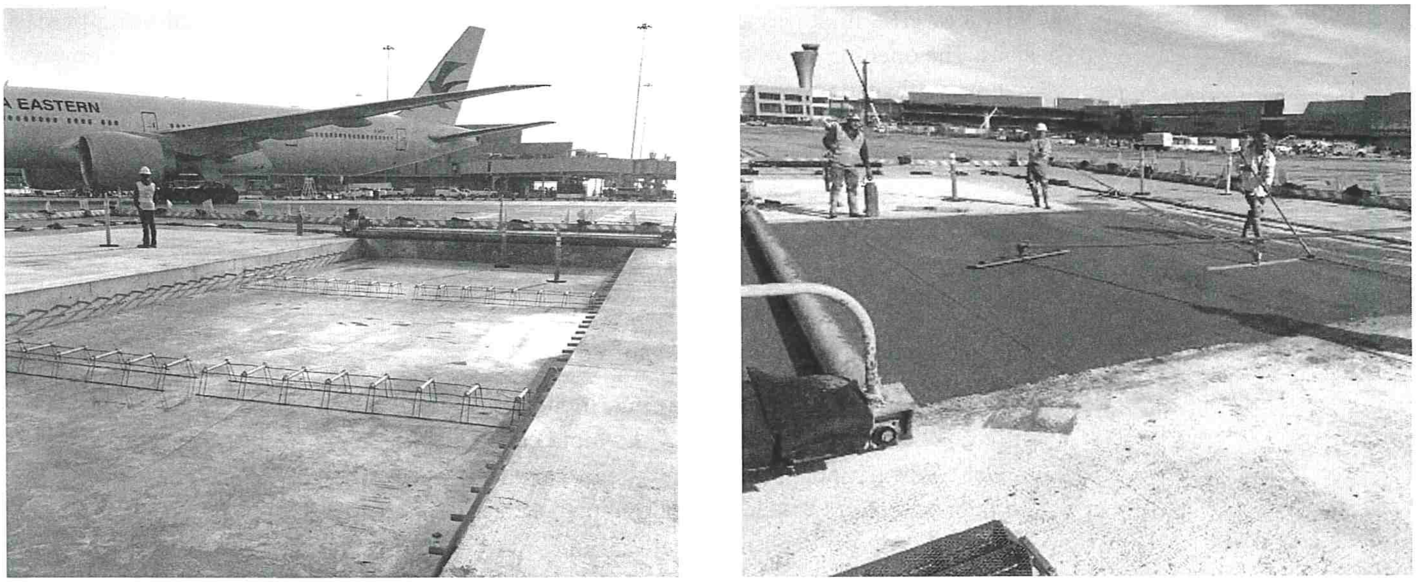
(a)



(b)

Source: Nichols Consulting Engineers, Chtd.

Figure 2. Example of partial-depth repair on an airfield (damaged electrical conduit; not a dowel bar): (a) prepared repair area and (b) installed repair material.



(a) (b)

Source: Nichols Consulting Engineers, Chtd.

Figure 3. Example of cast-in-place full-depth repair on an airfield: (a) repair area ready for concrete placement and (b) concrete finishing.

  - **Moderate-early-strength (MES) concrete:** Concrete mixture with an opening-to-traffic time of 20 to 36 hours.
- **Design–bid–build:** Project delivery method in which design documents are prepared in advance, competitively bid, and the bidder with the lowest price is typically awarded the contract to carry out the work.
- **Job-order contract:** Fixed-price contract with established unit prices for work items listed in the scope, a specified term (typically multiyear), and a not-to-exceed contract value. This type of contract is competitively bid and can have multiple contractors.

Current Industry Trends

Survey responses from individuals affiliated with 21 airports revealed the following industry trends regarding PDR and FDR that helped shape this report:

- Most PDRs and FDRs are performed on aprons, followed by taxiways and runways.
- Nearly all PDRs and FDRs are done under nonemergency conditions and are typically performed by contractors. Nonemergency work is delivered under a variety of contracting mechanisms. Traditional design–bid–build, job-order contracting, and solicited quotes are the most common methods.
- Fewer than half of the respondents use PDR or FDR in emergency conditions. Emergency work is generally delivered by soliciting quotes or through job-order contracting. Other delivery methods mentioned include work done by airport personnel, change order to existing contract, and through annual maintenance contracts.
- Runway PDRs and FDRs are most often constructed during overnight or weekend closures on airports with multiple runways. Most work at runway intersections is completed overnight. Aprons have the lowest overnight closure requirements for PDRs or FDRs.
- Prepackaged VHES or HES cementitious materials are the most frequently used material for PDR.

- VHES or HES mixtures are often used for FDR. Two respondents reported using precast slabs. The opening times for FDRs are commonly determined through flexural or compressive strength testing.
- In general, design plans and specifications are prepared for nonemergency work. For emergency work, some airports provide specifications and standard details, and a few airports follow contractor recommendations.

Overview

The remainder of this report is organized as follows:

- Chapter 2 discusses RSRR planning, including identifying the need for PDR and FDR, differences between conventional and rapid construction, the RSRR decision process, stakeholder coordination, project delivery approach, and project design needs.
- Chapter 3 provides detailed guidance for PDR.
- Chapter 4 provides detailed guidance for FDR.
- Chapter 5 provides conclusions and suggestions for future work.

Profiles of RSRR programs at airports, along with case examples of PDR and FDR construction, are provided in Appendix A and Appendix B, respectively.

CHAPTER 2

Planning

Thorough planning is essential for the success of any RSRR project. This process begins by identifying an individual or team (depending on project size) to oversee the planning process. There are six key steps in a typical planning sequence for RSRR projects (Figure 4). The level of effort within each step will vary from airport to airport according to the airport size, type, function, and available resources; experience with RSRR; and the quantity and location of RSRR work. For example, Steps 2 and 3 are more applicable to airports that do not regularly perform or have not performed RSRR, whereas those two steps may be skipped by airports that have extensive RSRR experience or established programs. While airports will develop individualized approaches to planning, the general planning sequence remains the same.

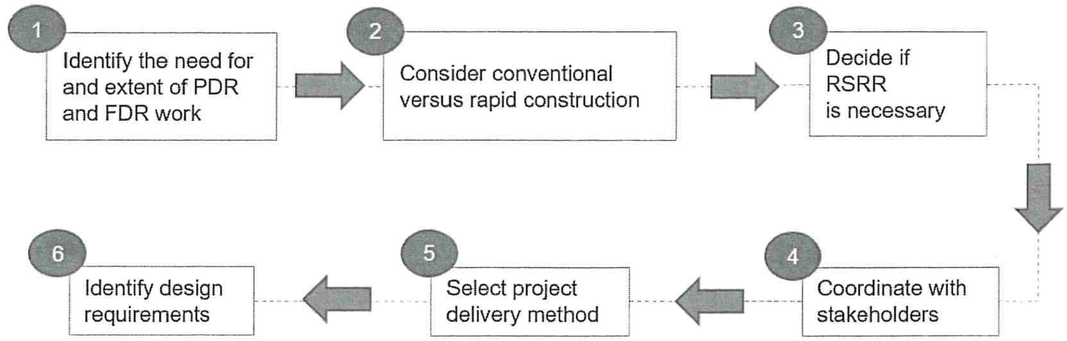
Identify Need for and Extent of Partial- and Full-Depth Repair Work

Selecting applicable and effective maintenance treatments depends on factors such as existing distress, facility type, climate conditions, available materials, and access to experienced personnel to conduct the work. The steps are

1. Conduct a detailed pavement assessment to identify concrete pavement distresses (type, extent, and severity).
2. Determine whether PDR or FDR is the proper repair strategy for the observed distresses.
3. Document the size and location of proposed PDRs and FDRs.

One or more of the following methods (listed in order of increasing amount of inspection detail and required resources) may be used to determine whether concrete slabs need repair or replacement (either PDR or FDR):

- **Visual pavement inspections** carried out by airport personnel on a regular basis:
  - For Part 139 airports, guidance is provided in FAA AC 150/5200-18C, *Airport Safety Self-Inspection* (FAA 2004).
  - For non–Part 139 airports, pavement-related inspection guidance listed in FAA AC 150/5200-18C can be useful, albeit on a less frequent inspection schedule.
- **Pavement surface evaluation and rating of specific pavement areas** per FAA AC 150/5320-17A, *Airfield Pavement Surface Evaluation and Rating Manuals* (FAA 2014a). Additionally, FAA AC 150/5380-6C, *Guidelines and Procedures for Maintenance of Airport Pavements* (FAA 2014b) provides guidance on the inspection of pavements and identification of concrete pavement distresses.
- **Detailed inspection of pavement condition**, carried out according to ASTM D5340, "Standard Test Method for Airport Pavement Condition Index Surveys." This method must



Source: Nichols Consulting Engineers, Chtd.

Figure 4. Planning sequence.

be expanded to the entire pavement area of interest to determine locations and quantities of PDRs and FDRs. If data are being collected specifically for an RSRR project, the pavement condition index (PCI) does not need to be calculated, as the location and extent of distress are more important. Detailed distress mapping, which can often incorporate geographic information system data for locating and tracking repairs, is suggested.

- **Information extracted from an Airport Pavement Management Program** populated with data collected according to ASTM D5340. These programs, however, are often based on statistical analysis of sample units, which may not accurately identify the actual repair quantities.

Following are examples of approaches for determining the need for PDR and FDR:

- John Glenn Columbus International Airport: A pavement condition assessment is performed on an annual basis and used to determine PDR quantities. The airport operations group determines whether an emergency repair is warranted.
- Louisville Muhammad Ali International Airport: Visual pavement inspections are performed on a regular basis, and the airport has established thresholds for cracking and spalling distresses that trigger repair strategies.
- McCarran International Airport (Las Vegas): Weekly inspections are performed to identify locations that require PDR and FDR. If areas that need PDR are identified, they are programmed for repair the following week. Locations that warrant FDR or other major repairs are discussed with FAA on a weekly basis to program the repairs. One highlight of the program is that the cause of failure is investigated to identify the correct repair strategy and minimize the chance of repeat failures.
- Raleigh–Durham International Airport: A pavement management system is used to track distresses, the PCI, and deflection measurements to evaluate structural capacity. Airport personnel use the pavement management data to track performance and identify areas for repair. Pavement condition surveys are conducted on one-third of the pavements each year.
- Seattle–Tacoma International Airport: One-third of the airfield pavement assets (e.g., runways, taxiways, taxilanes, and aprons) are inspected each year. These data are integrated into a 5-year pavement management program that is used to prioritize pavement work.

Consider Conventional Versus Rapid Construction

The selection of the construction technique to be used for PDR and FDR application is driven mainly by the location of work on the airfield, the impact on airport operations, and the allowable closure time. Rapid construction is not always necessary and, before deciding on a construction technique, it is essential to

1. Develop a basic understanding of the differences between conventional and rapid PDR and FDR construction and
2. Understand the challenges associated with rapid PDR and FDR construction.

Considerations for selecting conventional or rapid construction techniques include overall approaches, construction duration, and typical materials, among others.

Construction Approaches

Conventional construction relies on common construction techniques and equipment, standard work hours, and readily available materials. Equipment and materials (e.g., concrete mixtures) are widely available because they are used on local and regional construction projects (nonairport as well as airport projects). In comparison, rapid construction requires accelerated techniques, constrained work periods, backup equipment, and, often, concrete mixtures or repair products with early strength gain characteristics. Table 1 summarizes typical features of conventional and rapid construction approaches.

Duration of Construction

The duration of construction varies for PDR and FDR but is typically governed by the time required for the conventional portland cement–based materials to achieve the required strength for opening to traffic (i.e., 5 to 7 days or more).

Rapid construction is generally carried out in a short time window during specified hours (nighttime, off-peak hours, weekend, or multiday/multiweek closures). Some closures for emergency PDR may be less than 2 hours, depending on the location of the pavement (e.g., runway). See the definitions provided in Chapter 1.

Table 1. Typical features of conventional and rapid slab repair and replacement construction.

Feature	Conventional Construction	Rapid Construction
Materials, techniques, and equipment	Contractors are familiar with materials and techniques.	Initial learning curve, as contractors may not be familiar with early-strength concrete materials and techniques. Fewer contractors have the necessary experience.
	Materials and equipment are readily available.	Requires specialty or less-common concrete mixtures and repair materials.
	Concrete mixtures require several days to gain required strength for opening.	Concrete mixtures can gain sufficient strength to open in less than a day or even within a few hours (shorter closures).
Operational impact	Larger impact on aircraft operations (depending on airfield location).	Reduced impact on aircraft operations (depending on airfield location).
Final product	Tends to have better workmanship and final product.	Workmanship and final product quality can suffer as a result of accelerated schedule.
Cost	Costs in line with industry standards for similar work.	Often higher costs (as compared with conventional construction).
Service life	Service life in line with industry standards for similar work.	Service life is often shorter (as compared with conventional construction).

Source: Peshkin et al. (2006), FAA (2007), Priddy et al. (2013), Priddy (2015), and data collected during this project.

Typical Materials

Although specific materials are not selected during the planning process, it is important to have a general understanding of the common material types for airfield PDR and FDR. Table 2 summarizes typical materials used for PDR and FDR along with typical timing for opening to traffic.

For material selection, Smith et al. (2014, p. 115) recommend "to use the least exotic (i.e., most conventional) material that will meet the opening [to traffic] requirements." It is important to consider the candidate material types used for PDR and FDR when planning the allowable closure times, especially if there is flexibility in closure times. If closure times for specific airfield pavements are already established (i.e., not flexible), PDR and FDR materials should be selected that achieve specified strengths within the allowable time constraints, including the time for construction.

Considerations

Proper remediation of poor subgrade may not be feasible during rapid construction, depending on the duration of closure (i.e., overnight, full-day, or weekend closures). The extent of required subgrade remediation should be considered when the duration of closure and need for rapid construction are being evaluated.

Other considerations that typically drive the decision to use rapid construction include

- Construction impact: Operational impacts (associated with the work location) almost always drive the decision to use rapid construction.
- Cost: The costs can be considerably higher than conventional construction costs because of accelerated schedules and the use of specialty materials.
- Performance: Increased risk of premature failure or shortened service life is inherent in rapid construction.

Table 3 expands on these points. The order of importance varies depending on the size of the airport. For example, construction impact is likely the most important factor for airports with

Table 2. Typical features of conventional and rapid slab repair and replacement construction.

Construction Approach	RSRR Type	Typical Materials	Timing of Typical Return to Service After Installation
Conventional	PDR	Conventional concrete or mortar materials.	≥3 days
	FDR	Conventional concrete (e.g., P-501 or local concrete mixture, if permitted).	≥7 days
Rapid	PDR	Specialty VHES materials with cementitious or noncementitious binders. Typically, proprietary, prepackaged materials with specific blending processes.	≤4 hours
		HES or MES portland cement–based concrete mixtures with an ASTM C494 accelerating admixture, a higher amount of portland cement, or a combination of both.	6–36 hours
	FDR	Commercially available ASTM C1600 VHES cements (critical pavement areas with very short closure windows).	≤4 hours
		HES or MES portland cement–based concrete mixtures with an ASTM C494 accelerating admixture, a higher amount of portland cement, or a combination of both.	6–36 hours

Table 3. Considerations for rapid PDR and FDR construction.

Factor	Impact
Construction	Operational impact almost always drives the need for rapid PDR and FDR construction. • Conventional construction methods and materials are not an option for hourly, overnight, and full-day closures as these materials cannot achieve required strength (i.e., needed to support aircraft loads) in these time frames. • Weekend closures may permit the use of some aspects of conventional construction methods (e.g., daytime construction) and materials (e.g., conventional concrete with accelerators). • With proper planning, some pavement areas (e.g., aprons, taxiways with alternate routes, or runways at multirunway airports) may be candidates for the use of conventional construction methods and materials.
Cost	Accelerated schedules and use of specialty materials result in higher construction costs. • Seattle–Tacoma International Airport reports early-strength concrete can be up to 7 times more expensive than conventional concrete. • Vancouver International Airport reports the use of precast slab replacement for a pilot project was much more expensive than conventional cast-in-place but was a feasible alternative due to time restrictions. FAA AC 150/5370-16 (FAA 2007) lists the following factors related to increased cost: • Requirement for standby equipment and operators. • Increased contractor, inspection, and testing labor costs due to standard overtime and premiums for night and weekend work. • Lighting for night work. Additional factors increasing costs include: • Material costs for prepackaged materials used for PDR. • Material costs for HES materials used for FDR. • Added risk to contractor associated with accelerated construction. • Direct costs to airport (i.e., overtime for operations and construction personnel). • Larger workforce required.
Performance	PDRs and FDRs constructed using conventional techniques and materials inherently have lower risks of premature failure or shorter service life (Frentress and Harrington 2012, Hammons and Saeed 2010, Peshkin et al. 2006, FAA 2007). In comparison, accelerated construction comes with increased risk of premature failure and shorter service life. Factors that can lead to shortened service life include: • Poor workmanship. • Lack of experience with early-strength materials (e.g., improper mixing, handling, installing, and curing early-strength materials). • Shrinkage associated with some early-strength materials. • Nighttime construction. • Rushed nature of rapid construction. – Lack of contractor adherence to specifications. – Relaxed enforcement of project specifications. – Relaxed construction oversight.

significant commercial service. In comparison, cost may be more important to general aviation airports with limited budgets.

Table 4 presents examples of service life reported by airports included in this study.

Decide Whether Rapid Slab Repair and Replacement Is Necessary

Table 5 provides criteria to determine whether RSRR is necessary.

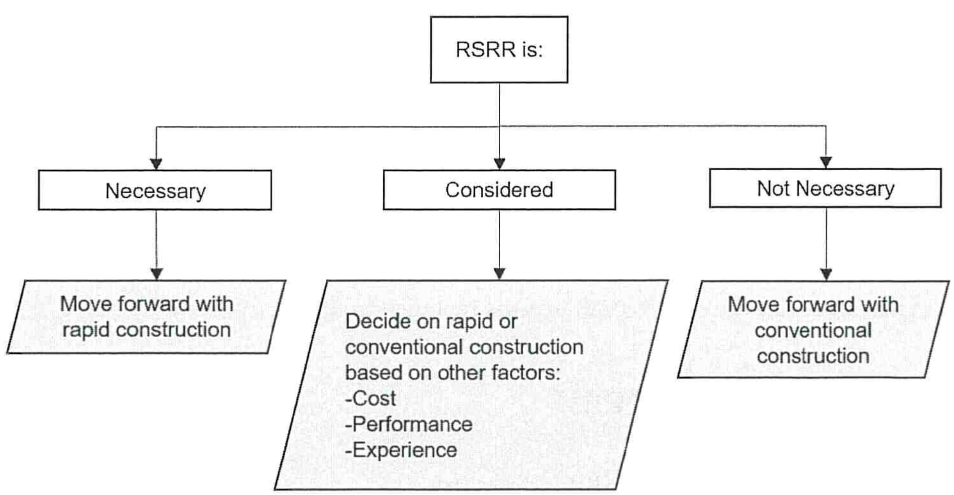
Once a selection has been made from Table 5, the flowchart presented in Figure 5 can be used to determine how to move forward. Ultimately, the decision to utilize rapid construction for PDR and FDR lies with each airport.

Table 4. Reported service life for PDR and FDR.

Airport	Performance Life
Hartsfield–Jackson Atlanta International Airport	• PDR: 5 years
McCarran International Airport	• PDR: Several years; however, repairs get damaged during rubber removal • FDR: 3–5 years
Phoenix Sky Harbor International Airport	• PDR: 9 months to 3 years • FDR: Performs well and repair life not a concern
Vancouver International Airport	• FDR: >10 years

Table 5. Criteria for deciding whether rapid slab repair and replacement is necessary.

Evaluation of Need for RSRR	Criteria	Examples
Necessary	• Emergency PDR at any location. • Work location (PDR or FDR) will significantly affect aircraft operations or airport capacity (alternate routes may or may not exist).	• Main runway or taxiway, aircraft parking location on apron or at a gate. • Single-runway airports.
Considered	• Nonemergency PDR at noncritical locations. • Work location (PDR or FDR) may inconvenience users with minimal impact on aircraft operations or airport capacity (alternate routes exist).	• Runway when multiple parallel runways exist. • Secondary parallel taxiway; aircraft parking location on apron or at a gate. • Cargo apron.
Not necessary	• Areas that can be closed to aircraft traffic for an extended period with minimal to no disruption to operations (alternate routes exist).	• Aprons. • Runway when multiple parallel runways exist. • Other noncritical concrete pavements.



Source: Nichols Consulting Engineers, Chtd.

Figure 5. Rapid construction decision flowchart.

Coordinate with Stakeholders

Regardless of the airport size and function, early engagement and continued coordination with stakeholders is an important planning element. This was identified by numerous airports surveyed during this project. Stakeholder coordination includes the following tasks:

- Identify stakeholders.
- Discuss project scope.
- Solicit input from stakeholders.
- Establish closure times and construction timing (i.e., preferred time of year or day of the week).

Identify Stakeholders

Stakeholders can be defined as groups or businesses on which the project will have an impact. Stakeholders may need to provide resources (e.g., airport operations), adjust flight schedules (e.g., airlines), or plan for impacts to business (e.g., tenants). Examples of stakeholders include, but are not limited to, the following:

- FAA;
- Control tower and ground control;
- Airport operations, police, and aircraft rescue and fire fighting (ARFF);
- Airlines;
- Air cargo companies;
- Tenants (e.g., fixed-based operators, flight schools, private hangars, charter services);
- Ground services; and
- Air National Guard (or other military operations at a joint-use facility).

Discuss Project Scope

While all details may not be available until later in the planning and design process (if applicable), it is important to inform stakeholders about the general project scope as soon as possible. Examples of discussion items include

- Scope of work (e.g., PDR, FDR),
- Work areas and closure limits, and
- Duration and timing of work.

Information can be initially conveyed in written format (e.g., letter or memorandum) to inform stakeholders about the upcoming project. However, as the planning and design process advances, meetings outlining the proposed plans and approach may be a more effective way to solicit and receive stakeholder input.

Establish Closure Times and Construction Timing

A key element of the planning process is establishing allowable closure times by RSRR location (e.g., runway, taxiway, apron) and construction timing (i.e., preferred days, months, etc.). Two cases exist:

- Established closure times for different pavements on the airfield (i.e., runway, taxiway, apron) already exist. In this case, typical closure times should be identified and reviewed with stakeholders.
- Established closure times for different pavements on the airfield do not exist. In this case, closure times will need to be established with input from stakeholders. While stakeholder input is important, the airport must ultimately make the final decision on preferred closure

Table 6. Examples of stakeholder coordination.

Airport	Description
Hartsfield–Jackson Atlanta International Airport	Coordinates extensively with stakeholders to identify closure times.
Los Angeles International Airport	Engages stakeholders early in planning and meets regularly with FAA and airline representatives.
Louisville Muhammad Ali International Airport	Coordinates significantly with all stakeholders by conducting preconstruction meetings and weekly go/no-go meetings with cargo carriers.
Raleigh–Durham International Airport	Coordinates with airline operations and works with them to determine flexible closure times. Holds monthly meetings with stakeholders to keep them informed and updated on the projects.

times given the constraints. Selection of time must also consider weather conditions favorable for RSRR construction and materials to achieve the intended service life (i.e., short-term or long-term).

All closure options for conventional slab repair and replacement or RSRR with longer construction time frames (1-day closure or weekend closure) should be fully investigated before an overnight closure option is considered (as previously discussed, materials and construction techniques associated with overnight closures are often more costly, and the risk of premature failure may increase).

Depending on airport size, investigation into permitting longer closure times may require extensive coordination with stakeholders on such things as

- Timing of scheduled flights and ability to adjust schedules;
- Terminal gate access and aircraft parking positions;
- Airside access to airfield tenants;
- Alternate aircraft taxi routes around construction;
- Alternate arrival and departure runways;
- Loss of revenue to airport and tenants;
- Emergency access routes for ARFF, police, and airport operations; and
- Construction cost and quality.

Factors to consider when discussing overall timing of RSRR construction include

- Time of year with favorable weather conditions for construction;
- Seasons with lower aircraft operations (passenger and cargo);
- Times, days, weeks, or months with lower aircraft operations (passenger and cargo);
- Conflicts with larger airport construction projects (i.e., schedule, location); and
- Ability to simultaneously carry out work under a previously planned closure, which may require less overall stakeholder coordination.

Table 6 provides examples of stakeholder coordination done by airports included in this study.

Select Project Delivery Method

Project delivery is the process and contract mechanism used to select the individuals or firm that will design and install the repair. Project delivery options for contractor-delivered projects include competitive bids, job-order contracting, executing a change order to existing contracts,

and soliciting quotes. A contract is not required when the work is performed by airport personnel. The main objectives and outcomes of this portion of the planning process are to

- Decide who will perform the construction work (e.g., airport personnel or outside contractor) and whether a contract or agreement is required and
- Evaluate options and determine the solicitation and contracting method to deliver the RSRR project.

Figure 6 is a flowchart of the project delivery decision process.

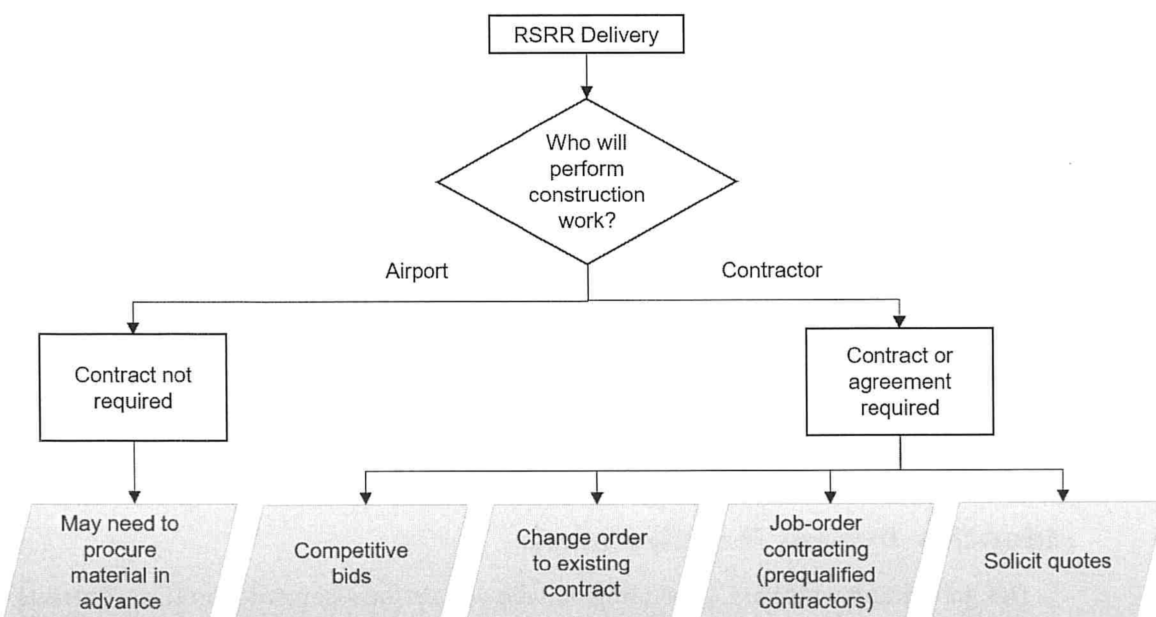
Decide Who Will Perform Construction Work

An airport should first assess its ability to perform PDR and FDR construction work. The following factors can influence this decision:

- Experience: Airport staff should have experience with the type of work (PDR or FDR) that is being proposed. Experience with FDR is rare outside of large hub airports.
- Equipment: The airport must have proper equipment. PDR work requires certain equipment (e.g., jackhammers, concrete saws), some of which is specific to the selected repair material. FDR requires specialty heavy equipment (e.g., excavators, dump trucks, concrete screeds).
- Staff availability: The airport must have sufficient staff with PDR or FDR experience available during the required time frame.
- Project size: The airport must have available staff and equipment with which to complete the required number of PDRs or FDRs within the specified duration of the construction.

Airports that do not have personnel with RSRR experience or the necessary equipment will need to hire a contractor for emergency and nonemergency PDRs and FDRs. Airports that do have both personnel with RSRR experience and the equipment necessary to complete the work may perform PDR and FDR themselves or choose to hire a contractor to perform the work. The following factors can influence this decision:

- Urgency of the work: The airport survey responses indicated that most emergency PDRs and some nonemergency PDRs are performed by airport personnel. FDRs are rarely done in



Source: Nichols Consulting Engineers, Chtd.

Figure 6. Project delivery flowchart for rapid slab repair and replacement.

Table 7. Types and applications of project delivery approaches.

Type	Application	Notes
Competitive bid	Common method for nonemergency RSRR (any size project).	Part of traditional design–bid–build project delivery.
Change order to existing contract	Feasible for nonemergency or emergency RSRR (smaller projects).	Pricing may be higher than competitive bidding. Ensure the contractor or subcontractor has the proper experience to perform RSRR work on the airfield.
Job-order contracting	Nonemergency RSRR at airports with access to a pool of on-call, prequalified contractors (medium and larger projects).	Generally available to airports that are owned or operated by agencies (e.g., cities, counties, or state transportation departments). Unit pricing for typical work items is commonly established in advance.
Solicit quotes	Emergency or nonemergency RSRR (very small projects).	Reserved for cases when local contractors have previously performed RSRR work at the airport (or similar airport).

emergency situations, but a few large airports have the personnel and equipment to do this work in house.

- Quantity of work: The surveyed airports tend to hire contractors for larger PDR projects. However, contractors generally perform all FDRs, even for projects as small as 1 to 2 slabs.
- Availability of personnel: Airport personnel may not be available for RSRR within the required time frame.
- Availability of equipment: The airport must have sufficient equipment available to complete the required number of PDRs or FDRs within the specified duration of construction. Materials and equipment may need to be procured well in advance of construction.

Select Contract Type

If the decision is made for a contractor to perform the RSRR work, a contract or agreement is necessary. Materials and equipment are normally provided by the contractor, but, in rare cases, the airport may provide the materials for the contractor to install. When a contract or agreement is warranted, four main construction solicitation and delivery approaches are common for RSRR projects:

- Competitive bids as part of a traditional design–bid–build project delivery approach;
- A change order to an existing contract for work at the airport;
- Job-order contracting from a pool of on-call, prequalified contractors; and
- Soliciting quotes from local contractors who have previously performed RSRR work at the airport (or at a similar airport).

Table 7 provides more detail on the typical application of project delivery approaches. Table 8 provides examples of delivery approaches used successfully by airports included in this study.

Identify Design Requirements

Design requirements vary, depending on who will perform construction (i.e., contractor or airport personnel), the size of the project, and the type of construction contract. Design plans and specifications may be required, or a set of standard details may be utilized. The main objectives and outcomes of this portion of the planning process are to

Table 8. Delivery approach.

Airport	Delivery Approach
Hartsfield–Jackson Atlanta International Airport	Design–bid–build
Los Angeles International Airport	Design–bid–build and competitive bids
Louisville Muhammad Ali International Airport	Design–bid–build
McCarran International Airport	Airport maintenance crew and change order to existing contracts
Phoenix Sky Harbor International Airport	Airport maintenance crew for PDR and on-call contractor for other jobs
Raleigh–Durham International Airport	Design and Construction Manager at-Risk[a]
Seattle–Tacoma International Airport	Design–bid–build with change order to existing contract
Vancouver International Airport	Design–bid–build and construction manager[a]

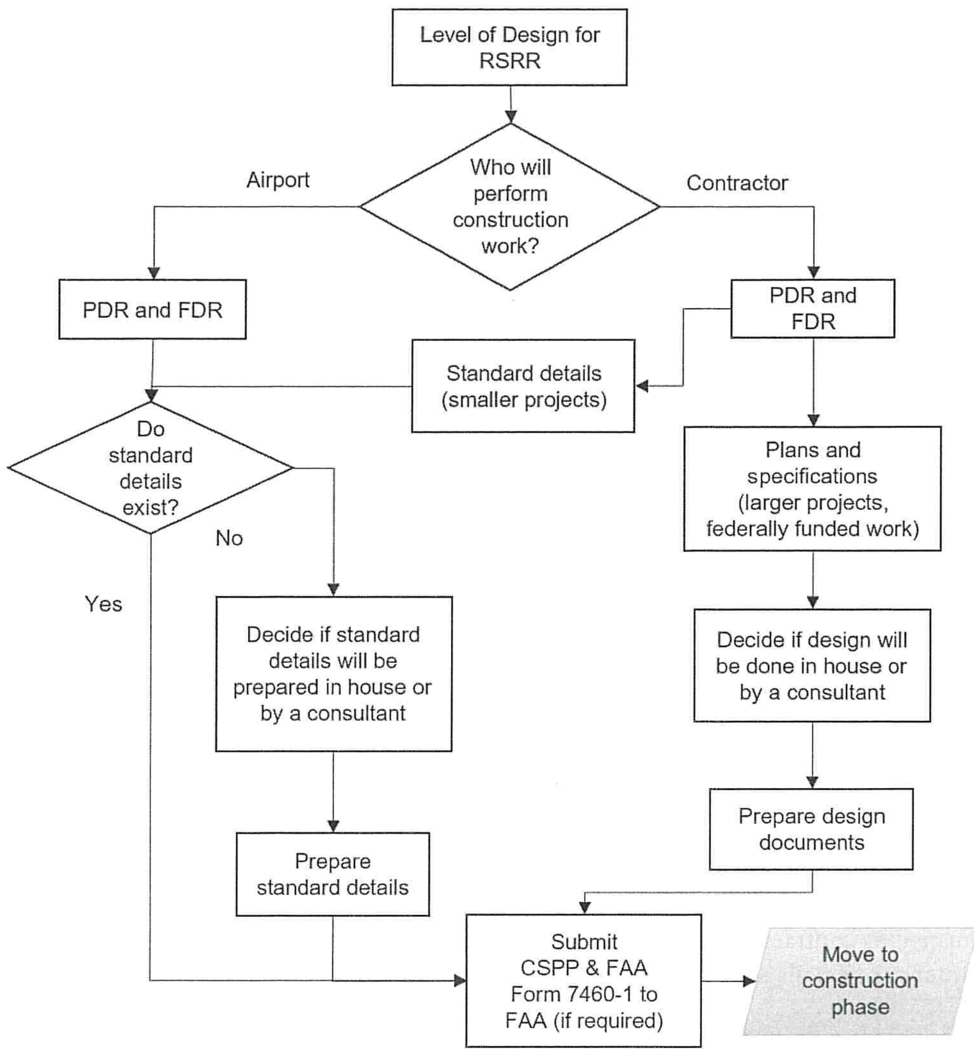
[a]Large-scale RSRR projects.

- Decide the level and extent of design needed for the project (such as complete drawing sets or just standard or generic details) and
- Determine who will perform design services (airport or consultant).

Data collected for this project revealed the following trends related to the level of design for RSRR projects:

- Construction is performed by airport personnel:
  - Design details and construction procedures may or may not be formalized.
  - Design details from previous RSRR projects are sometimes used.
- Construction performed by contractors uses a combination of design documents (plans and specifications) and standard details/specifications; actual practice is a function of the project delivery approach:
  - Design plans and specifications are required when soliciting competitive bids (design–bid–build approach).
  - Change order to existing contract typically uses supplemental design plan sheets and specifications to detail the work.
  - Job-order contracting typically uses standard design details and specifications that were used to preestablish unit pricing.
  - Soliciting quotes typically uses standard design details and specifications. This information may be developed in house or may be taken from design plans from previous RSRR projects.

Figure 7 provides a flowchart of the design decision process. It is important to note that by their nature, emergency PDR and FDR do not allow time for the preparation of design documents or details. Standard details or standard operating procedures are typically used and should be developed in advance. If required, a construction safety and phasing plan (CSPP), along with FAA Form 7460-1, should be submitted to FAA.



Source: Nichols Consulting Engineers, Chtd.

Figure 7. Project design flowchart for rapid slab repair and replacement.

CHAPTER 3

Partial-Depth Repair

As defined in Chapter 1, PDR refers to the removal of small areas of damaged pavement contained within the top half of a concrete slab and replacement with a cementitious, polymeric, or other specialty repair material. PDR is a common practice to maintain and preserve concrete airfield pavements. When correct materials are selected and proper construction techniques are employed, PDR can be a cost-effective, long-term solution for concrete pavement repair needs. This chapter discusses the appropriate distresses, materials, design, and construction for a PDR project and presents an assessment tool to help users evaluate the considerations necessary to complete a successful PDR.

Introduction to Partial-Depth Repair

At airports, PDR is typically used to address concrete surface defects that can lead to FOD, which can damage aircraft or inhibit the safe passage of aircraft (Speer 2007, Hammons and Saeed 2010). However, PDR is also very important for preservation of concrete pavement. Spalling at joints, cracks, and midslab locations is the most common candidate for PDR [FAA 2014b, U.S. Department of Defense (DOD) 2018]. Spalling typically occurs when pieces of concrete are dislodged from a transverse crack or joint (or midslab). Figure 8 shows examples of spalling at joints and cracks and midpanel.

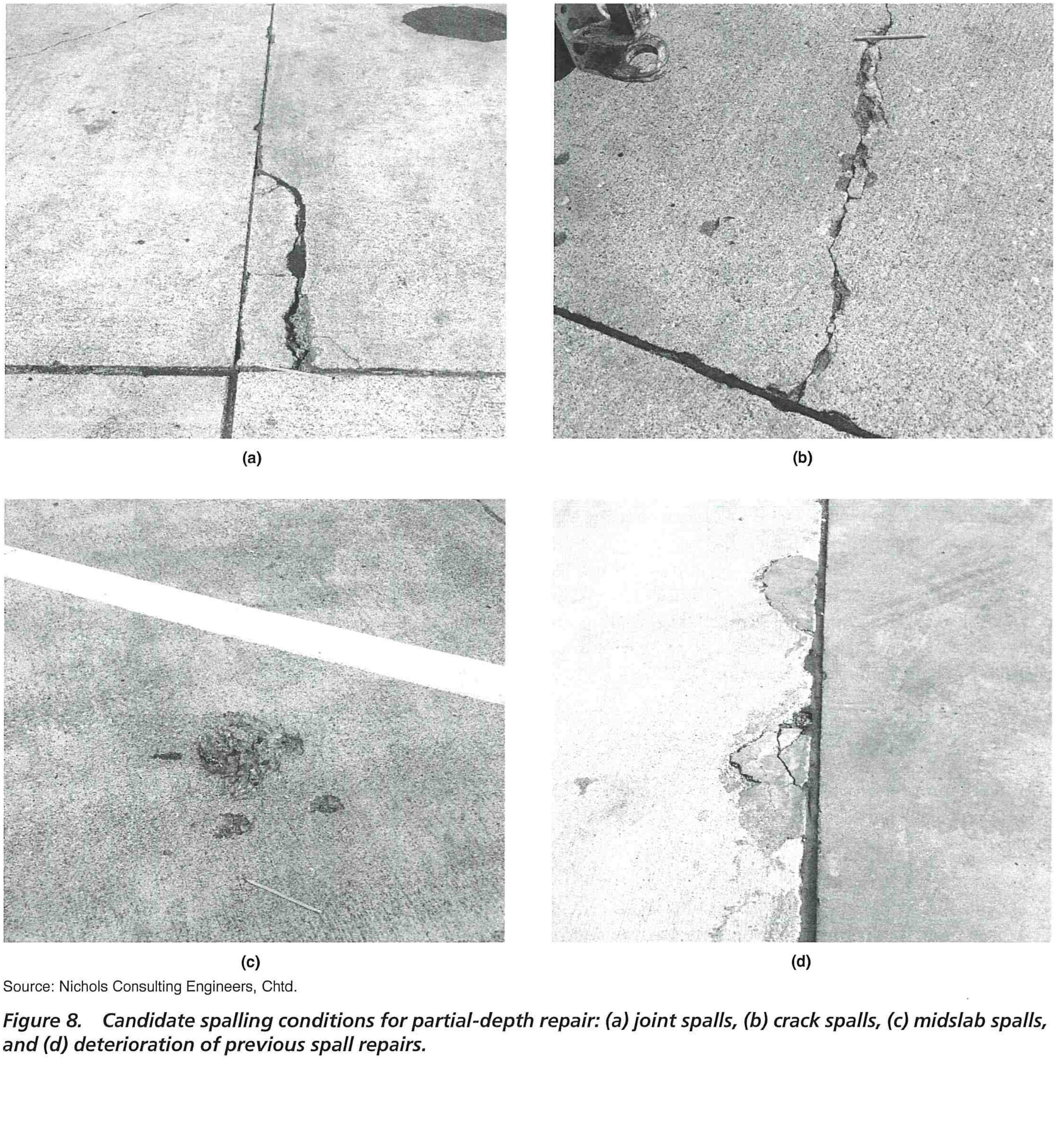
Candidate Distresses and Conditions

PDR is appropriate for addressing distresses that are confined to the top half of the slab and to relatively small surface areas. Distresses that have been successfully corrected with PDR include

- Spalling caused by the intrusion of incompressible materials into the joints;
- Spalling or raveling caused by poor consolidation or improper joint formation;
- Surface delamination or spalling caused by weak concrete, clay balls, or reinforcing steel located too close to the surface; and
- Spalling caused by lightning strikes and isolated to the top half of the slab.

PDR is not a long-term solution for correcting surface deterioration resulting from the following causes (Smith et al. 2014, U.S. DOD 2018):

- Improper finishing and curing during construction (e.g., shrinkage, map cracking),
- Environmental deterioration [e.g., freeze–thaw damage, durability cracking (D-cracking), scaling], and
- Undesirable chemical reaction (e.g., alkali–silica reactivity, alkali–carbonate reaction).



(a) (b) (c) (d)

Source: Nichols Consulting Engineers, Chtd.

Figure 8. Candidate spalling conditions for partial-depth repair: (a) joint spalls, (b) crack spalls, (c) midslab spalls, and (d) deterioration of previous spall repairs.

There are, however, situations where these distresses present an immediate safety hazard (e.g., FOD or depression) and temporary PDRs have been effectively used as a stopgap measure until a long-term treatment can be planned and executed. In these cases, the primary purpose in addressing these conditions is to quickly restore pavement serviceability and to ensure overall safety.

Material Selection

Several materials are available for use with PDR, and, in general, PDR material specifications vary between agencies. FAA AC 150/5380-6C (FAA 2014b) and AC 150/5370-10H (FAA 2018) provide limited guidance on PDR patching materials. The U.S. Army Engineer Research and Development Center (ERDC) conducts extensive assessment of various proprietary PDR repair materials. Recent findings are detailed in *Evaluation of Concrete Spall Repair Materials* (Falls 2019) and *Evaluation of Rapid-Setting Cementitious Materials and Testing Protocol for Airfield Spall Repair* (Ramsey et al. 2020).

FAA AC 150/5380-6C (FAA 2014b) references use of P-501 cement concrete pavement, as well as state department of transportation (DOT) specifications for allowable materials. The U.S. DOD Unified Facilities Criteria for operations and maintenance (O&M), the *O&M Manual: Asphalt and Concrete Pavement Maintenance and Repair* (U.S. DOD 2018), classifies materials in three categories: cementitious, polymeric, and bituminous (generally regarded as a temporary repair material for concrete pavements). Cementitious materials are commonly based on ASTM C150 (Standard Specification for Portland Cement) Portland Cement Type I, but ASTM C150 Portland Cement Type III is allowed when the repair needs to be opened to traffic within 1 to 3 days after placement. Smith et al. (2014) list the following materials as possible options for PDR:

- Most repair material is produced with either ASTM C150 Portland Cement Type I (with set-accelerating admixture) or Portland Cement Type III. In addition to strength, consideration must be given to the following material properties that affect short- and long-term performance: coefficient of thermal expansion (CTE), elastic modulus, shrinkage, and bond strength. Some agencies have standard HES concrete mixtures for PDR, but there are also several commercially available proprietary mixtures.
- Modified hydraulic cement concrete includes concrete made with modified cement, gypsum-based cement, calcium aluminate cement, calcium sulfoaluminate (CSA) cement, and other hydraulic cement–based mixes, most of which meet ASTM C1600 requirements.
- Gypsum-based cements have very quick set times, are resistant to deicing chemicals, and typically require dry installation conditions.
- CSA cements are a modified derivative of portland cement clinker; they exhibit rapid strength gain, good durability, low shrinkage, and high sulfate resistance.
- Calcium aluminate cements are similar to CSA, having rapid strength gain, good bonding properties, and good resistance to freeze–thaw cycles and deicing chemicals and exhibiting low shrinkage. However, concrete made from calcium aluminate cements undergoes a phenomenon called conversion, during which a portion of the concrete strength is lost. The mix design should be evaluated with a conversion test to ensure the converted strength exceeds the specified strength (Adams 2015).
- Polymer-based and resinous concrete are combinations of polymer resins, an initiator, and, often, aggregate. The aggregate is added as a filler and reduces costs, provides a durable wearing surface, and makes the thermal characteristics (as assessed by CTE) more consistent with that of concrete. Polymers exhibit faster strength gain than typical cementitious materials but can be expensive and sensitive to temperature and moisture. Some of these

repair materials are very flexible and can be placed across joints and cracks without the need to reestablish the joint. Urethane resins and epoxies are common polymers used for pavement repair applications.

- Polyurethanes are two-component materials that are very flexible and typically exhibit rapid strength gain. However, these materials are known to have very high CTE values, can be very sensitive to mixing and moisture, and exhibit large initial shrinkage.
- Epoxy polymer concretes typically have very good adhesive capabilities and are impermeable. However, these products have a wide range of bonding capabilities, setting times, application temperatures, and strengths. They also exhibit high CTE values, and compatibility with concrete needs to be considered.
- Magnesium-phosphate concrete is a very rapid-setting material with HES gain. Materials are impermeable but very sensitive to water (in the mix or on the repair surface). Clean, dry surfaces are needed for bonding. Workability can be a challenge in hot weather due to short set times, but some of the products are specially formulated for hot-weather applications.
- Conventional or modified bituminous materials are low-cost, short-term, bituminous-based materials. They are easily applied and widely available and can be opened to traffic very quickly. Polymer-modified bituminous materials have shown better performance than unmodified materials but have a higher cost. These materials are typically considered to be temporary for PDR of concrete pavement, and the U.S. DOD *O&M Manual* (2018) does not allow bituminous materials for concrete airfield pavement PDR. For this reason, bituminous PDR materials are not considered further in this report.

The selection of repair materials for long-term PDR applications is based on several factors, including the specific application, environment, performance history, and facility opening-to-traffic requirements. Opening-to-traffic requirements are often the most important factor; however, products with very early opening times are more expensive. Factors to consider for PDR material selection include the following (Smith et al. 2014):

- Time available for construction and strength gain (i.e., closure time),
- Ambient conditions during and after placement,
- Repair material properties (e.g., CTE, shrinkage, bond strength),
- Material and installation costs,
- Handling and workability,
- Compatibility with the existing concrete pavement,
- Repair size and depth,
- Alignment of material performance capabilities and performance requirements (expectations) of the repair, and
- Project size or number of anticipated repairs.

Other factors not specifically mentioned by Smith et al. (2014) include

- Equipment requirements (and capabilities) for mixing and material application;
- Complexity of mixing and material application;
- Long-term durability, especially in harsh environments;
- Agency maintenance and contractor employee exposure and safety (i.e., hazards associated with materials); and
- Agency maintenance and contractor employee experience with the material.

Ultimately, three major factors need to be considered when a PDR material is being selected for airport pavement repairs: (1) closure time (minimizing operational delays), (2) compatibility with the surrounding concrete, and (3) long-term durability, especially in harsh environments.

As there are numerous commercial (and sometimes proprietary) products available for constructing PDRs, a material selection screening process that includes the following steps can be used:

- Assess the products on the basis of project needs and conditions by reviewing product literature and talking with manufacturer representatives.
- Obtain airport references from the manufacturer and speak with previous users of the product. It is often best to contact similarly sized airports and inquire about products used, lessons learned, and recommendations.
- Request that the manufacturer provide a demonstration by installing the materials in non-critical areas before they are used in operation-critical locations.

One airport agency commented that the materials used for PDR do not necessarily need to be the most expensive or the newest on the market. Rather, it is important to identify and use the product that best suits the needs of the airport and the knowledge and skills of the personnel who will mix, handle, and install the product.

HES materials can be difficult to handle and install. Even if construction crews have experience, they should demonstrate their ability to properly install the materials off-site or start work on the least critical areas (e.g., aprons) before moving to critical areas (e.g., runways). These materials can be very sensitive to weather conditions during installation and curing; manufacturer's recommendations should be followed.

Design

PDR projects may or may not use detailed plans and specifications. The design process differs depending on the extent and nature of the PDR (i.e., emergency versus nonemergency). Emergency repairs generally rely on standard details and materials on hand. For larger PDR projects, plans and specifications can be used (particularly for bidding), but the use of standard details is more common. Following are some considerations, particularly for larger PDR projects:

- **Material requirements:** FAA AC 150/5380-6C references the use of P-501 cement concrete pavement or state DOT materials for PDR (FAA 2014b). Proprietary material specifications are often provided by the manufacturer. PDR material requirements commonly focus on strength gain and final strength, bond strength, shrinkage, CTE, and other important properties.
- **Provisions for disincentives when repairs affect critical airport operations:** Provide incentives for early completion. Penalties for not returning pavement to service are generally much more severe for runways (e.g., \$500/minute) but can be applied to other areas if they are critical to operations. Small PDRs are likely to be completed within the allotted closure, especially if an appropriate material is selected.
- **Plan details:** Design should include plan dimensions and depth details, but requirements can vary by product. Design efforts also need to consider contingencies in case some of the PDR locations are determined during construction to be better candidates for FDR.
- **Quality control/quality assurance (QC/QA):** Because batch sizes are generally quite small, extensive material testing is not practical. QC/QA for PDR is more often based on observations of means and methods, such as verifying preparation steps, material mixing and handling, finishing, and curing methods.
- **Opening-to-traffic requirements:** Opening to traffic is often based on time. This is because material testing is commonly less extensive for PDR than FDR or other large concrete placements. Often a prescriptive number of hours or days is used as the opening criterion when

work is being done within certain specified temperature conditions. The required times can be established during the mix design stage for cementitious products or established by the manufacturer.

- **Provision for a preconstruction conference:** It is advisable to hold a preconstruction meeting prior to closing pavement areas and allowing construction work to proceed. Confirming work methods, personnel responsibilities, site safety, and security are significant factors in the success of PDR projects.
- **Requirement for just-in-time training:** This training should cover product specifics and include a provision for a product installation demonstration on a noncritical pavement area (or off-site). This is especially important when new repair materials are being used, especially early-strength materials.

Construction

In general, steps for PDR construction are provided by Hajek et al. (2011), Frentress and Harrington (2012), Smith et al. (2014), FAA (2014b), the U.S. Air Force (USAF 2017), and the U.S. DOD (2018) and are as follows:

1. Determine and mark repair boundaries (confirm design plans).
2. Demolish and remove concrete.
3. Clean and prepare repair area.
4. Reestablish joint, as needed.
5. Place and consolidate repair material.
6. Finish and cure repair.
7. Reseal joints, as needed.
8. Open to traffic.

Each step of the PDR construction process is further described in the following sections.

Boundary Selection and Marking

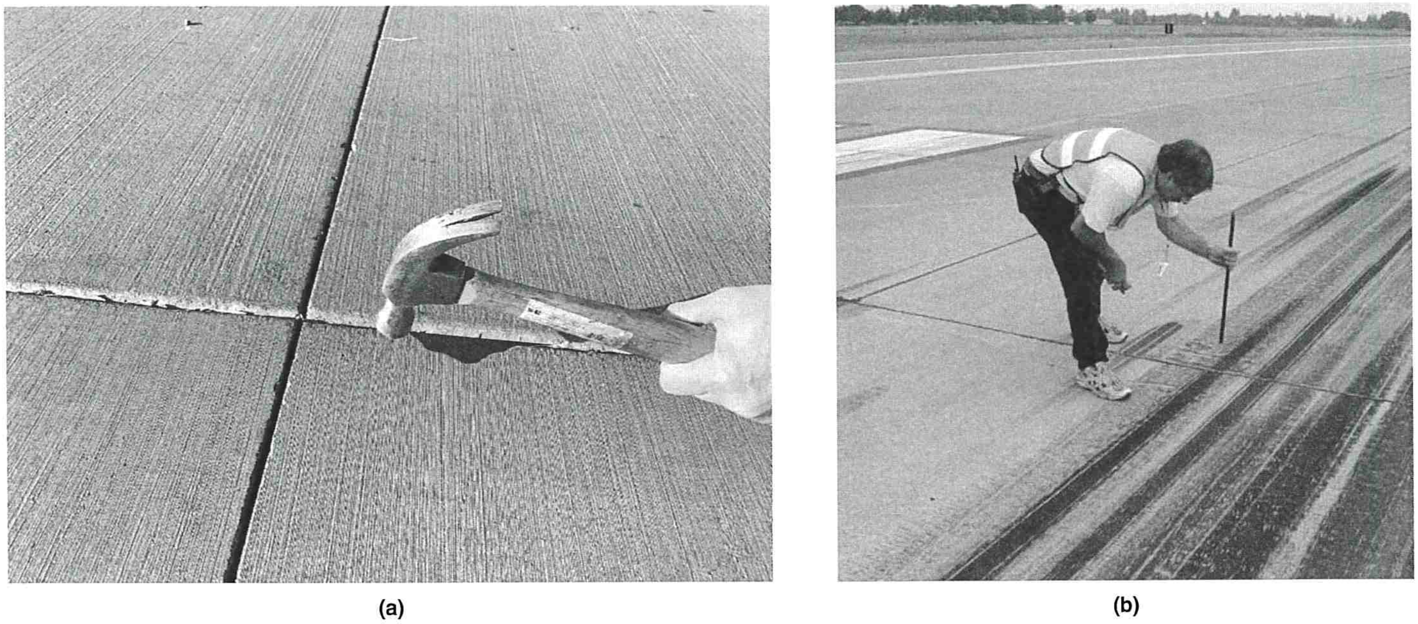
Aside from visual characterization of distress, the limits of deteriorated concrete can be determined by the sounding method, which consists of striking the concrete with a solid steel rod or a hammer and listening to the resulting sound. A dull sound is heard if the concrete is weak or delaminated, whereas a ringing sound is indicative of sound concrete. For larger areas, a chain drag or delamination detection tool can be used. Figure 9 shows examples of the sounding method.

Once the distressed area is identified, the repair boundary is established as follows for conventional cementitious repair materials (Wilson et al. 2001, Frentress and Harrington 2012, USAF 2017, U.S. DOD 2018):

- The boundary should extend at least 3 inches beyond the unsound concrete on all sides.
- The minimum repair length is 15 inches (the U.S. DOD recommends 6 inches).
- The minimum repair width is 10 inches (the U.S. DOD recommends 6 inches).
- The minimum repair depth is 2 inches and should extend 0.5 inch into visually sound concrete.
- Repair boundaries should be kept square or rectangular; irregular shapes are to be avoided.

Dimensions for PDRs that use a proprietary material should be in accordance with the manufacturer's recommendations.

The proximity of patches to one another should also be considered. FAA guidance suggests that spall repairs less than 1.5 feet apart should be combined into one repair (FAA 2014b). The



Source: (a) Nichols Consulting Engineers, Chtd., and (b) Applied Pavement Technology, Inc.

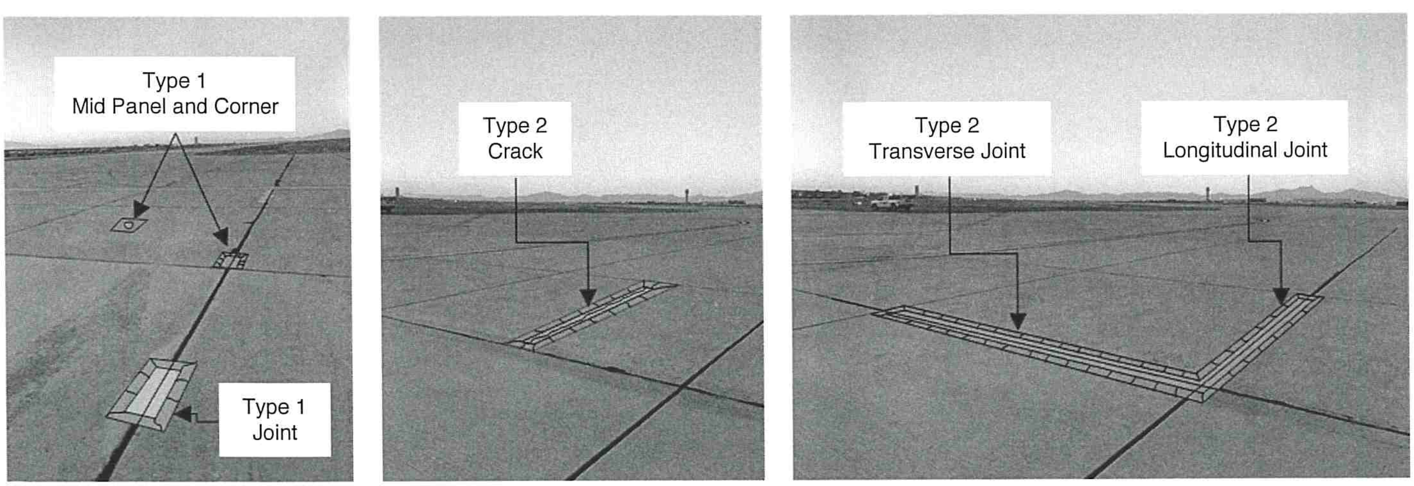
Figure 9. Sounding method using (a) hammer and (b) steel rod.

U.S. DOD (2018) provides similar guidance but indicates combining repairs if they are within 24 inches.

Repairs that are greater than half the thickness of the pavement are not candidates for PDR on an airport. If load-transfer devices are observed in the damaged area while marking boundaries, FDR is the appropriate repair option (see Chapter 4).

Concrete Demolition and Removal

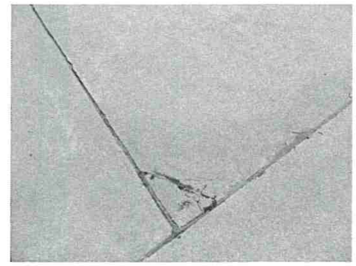
Once the repair area has been identified and marked, the damaged concrete within the repair boundaries is removed. Figure 10 shows schematic examples of different types of PDRs, and Table 9 provides basic descriptions and photos of each repair type.



Source: Nichols Consulting Engineers, Chtd.

Figure 10. Types of partial-depth repairs.

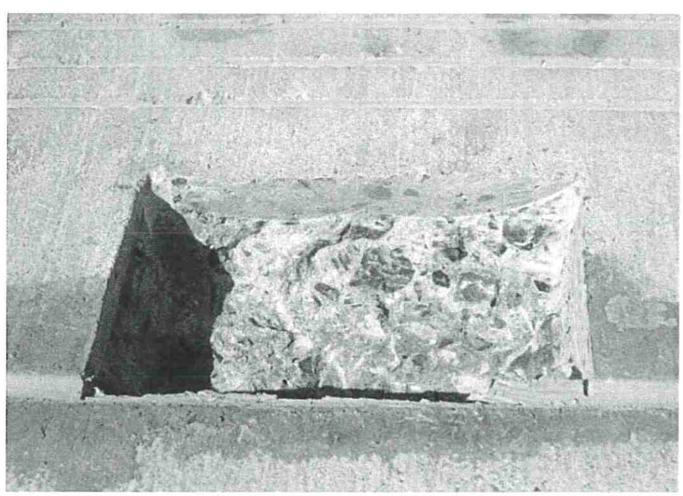
Table 9. Description of distress and appropriate PDR types.

PDR Type	Description	Example
1	Spot repairs (less than 6 feet in length). These are used to repair spalling at joints, corners, and slab interior. Applicable to repairs at transverse joints when load-transfer devices are still functional and not exposed.	
2	Repairs of extended length along a longitudinal or transverse joint or a crack longer than 6 feet.	

Source: Frentress and Harrington (2012) and Smith et al. (2014). All images provided by Applied Pavement Technology, Inc.

There are four general PDR removal methods: (1) saw and chip out, (2) chip out, (3) mill out, and (4) clean out (Smith et al. 2014).

1. **Saw and chip out:** A diamond-bladed saw is used to outline the repair boundaries (Figure 11). The depth of the cut usually extends to 2 inches. A light jackhammer (typically 15 pounds maximum weight, but up to 30 pounds if no damage to sound concrete is observed) is used to remove the concrete. The jackhammer can be carefully used to slightly chip the vertical polished saw cut edge to provide a rough surface to promote bonding between the patch repair material and the sound concrete.



Source: Nichols Consulting Engineers, Chtd.

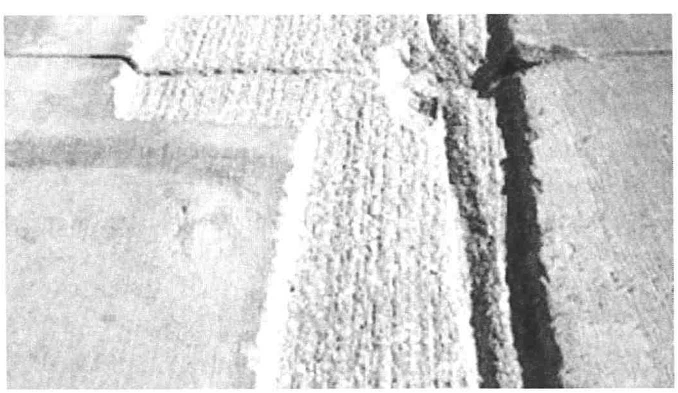
Figure 11. Saw and chip out.

Source: Nichols Consulting Engineers, Chtd.

Figure 12. Chip out.

2. **Chip out:** A light jackhammer (typically 15 pounds maximum weight, but up to 30 pounds if no damage is observed) is used to remove the damaged concrete, starting from the center of the repair area. The boundary edges are then removed at a slight angle with hand tools or a light jackhammer to avoid damaging sound concrete (Figure 12).
3. **Mill out:** A milling machine with a 12- to 18-inch-wide head is operated along the spalled area (Figure 13). The milling depth must be adjusted to remove all the damaged concrete material. This method is cost-effective, with the highest production rate of any method, and produces rough, uniform surfaces that promote bonding between the repair material and the existing concrete. Strong bonds result in good performance.
4. **Clean out:** Used only for emergency repairs, this method typically consists of removing the loose concrete with hand tools or a light jackhammer. The repair area is cleaned with stiff brooms.

FAA AC 150/5380-6C includes the use of saw and chip out (FAA 2014b). The U.S. DOD *O&M Manual* (2018) suggests both saw and chip out and mill out. Hammons and Saeed (2010) assessed expedient removal techniques and found that mill out (i.e., cold planer) achieved rapid preparation of the repair area.



Source: Frentress and Harrington (2012).

Figure 13. Mill out.

As previously stated, distresses that extend deeper than half the pavement thickness are not appropriate for PDR, particularly if load-transfer devices are exposed during concrete demolition and removal. If this occurs during construction, the load-transfer device should be cut through at the joint and a temporary PDR completed. This repair should be identified for future replacement with FDR (see Chapter 4).

Cleaning

Prior to placement of the PDR material, clean the exposed faces and bottom of the repair area to remove all loose particles, oil, dirt, dust, previous patch materials, and other contaminants. Thoroughly clean the area around the PDR with a power broom, vacuum sweeper, or hand broom to prevent debris from reentering the repair zone. Any contamination of the surface will reduce the bond between the PDR material and the existing concrete. FAA AC 150/5380-6C (FAA 2014b) indicates removing all loose material by hand, vacuuming, and cleaning the PDR area with high-pressure water. The U.S. DOD *O&M Manual* states, "as a minimum, air-blow with compressed air, wash with high-pressure water, and air-blow again" (2018, p. 102). Ensure the repair area is completely dried if high-pressure water is used to clean the repair area. Always follow the product manufacturer's recommendations, as they differ by the type of repair product.

Once the PDR area has been cleaned, the surface is prepared in accordance with the recommendations of the manufacturer of the repair material. For some cementitious materials, this may require applying a grout prior to placing the PDR material. If used, the grout must not set before the repair material is placed; otherwise, the repair will not bond to the substrate. Prepackaged materials may or may not require application of a liquid bonding agent. If a bonding agent is required, the manufacturer's recommendations must be followed.

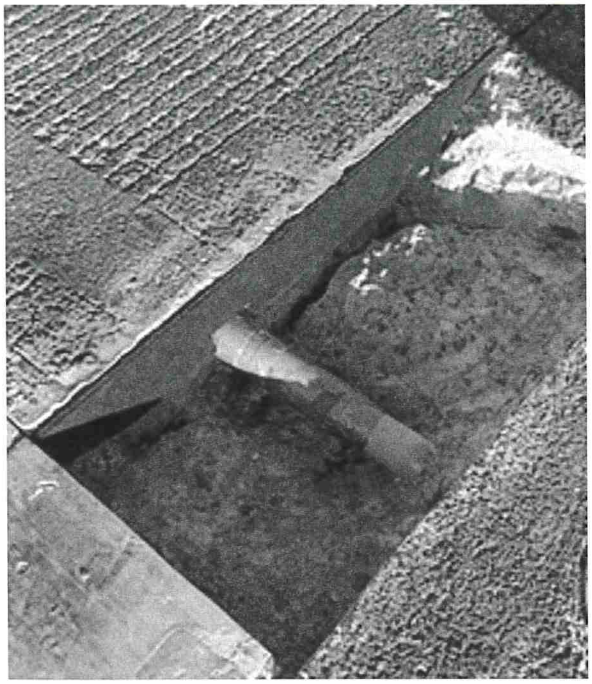
Reestablishing the Joint

PDRs that abut working joints or cracks that extend the full depth of the slab usually require that the crack or joint be reformed to prevent the repair material from contacting the abutting concrete and to ensure the repair material does not flow into the joint or crack. Failure to reestablish the joint or crack or allowing repair material to flow into it can cause stress points that may damage or dislodge the repair. A compressible insert or other bond-breaking medium is commonly inserted into the joint or crack to reform it and ensure that the repair material does not enter (Figure 14). As an alternative, the joint or crack can first be caulked to prevent material from entering and the compressible insert tacked into place to reestablish the joint or crack. Regardless of approach, the insert needs to be the full depth of the repair to avoid failure. Although reestablishing the joint or crack may not be required for some flexible proprietary materials, caulk should still be used to prevent the materials from entering.

Some agencies have established additional preparation requirements. One airport that participated in this study uses reinforcement in its PDRs. The detail includes tie bars arranged in a grid pattern that are drilled and grouted into the sound concrete (Figure 15).

Material Placement and Consolidation

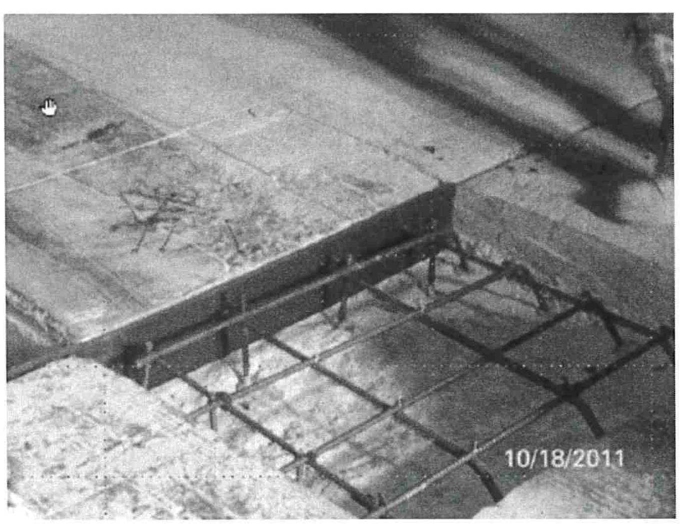
Production of PDR materials is different from that of materials produced for larger projects, such as slab replacements, because the quantity of material required per repair is much smaller (potentially 0.5 cubic feet or less). Transit mix trucks and other large equipment cannot efficiently produce such small quantities and would decrease the quality and result in waste of



Source: Nichols Consulting Engineers, Chtd.

Figure 14. Compressible insert at a joint (retrofitted electrical conduit shown; not a dowel bar).

material (U.S. DOD 2018). Because of the small quantity of material needed, it is common to mix cementitious PDR material on-site with a small drum or paddle mixer. For proprietary materials, the manufacturer's material preparation and placement instructions should be followed, particularly with regard to the size of repair and temperature. Some products are mixed in the container that they were shipped in. If material packaging is damaged, it should not be used.



Source: John Rone.

Figure 15. Reinforcing steel used in partial-depth repair.

Following are recommendations for placing repair materials (Frentress and Harrington 2012, Smith et al. 2014):

- Follow the manufacturer's recommendations for proprietary materials. Some materials must be placed in lifts, and some materials may be self-consolidating.
- For small patches, consolidate the material by rodding or tamping by hand.
- Work and float the material from the center of the patch toward the edges for better bonding with repair edges.
- Monitor air temperature and maintain compliance with material placement requirements (many materials should be used with air temperatures between 50°F and 90°F).

Material for large patches may be consolidated by using small spud vibrators. Vibrators greater than 1 inch in diameter are not recommended (U.S. DOD 2018).

Finishing and Curing

The surface of the repaired area must match the profile of the surrounding slabs. Texture should match that of the existing adjacent pavement; burlap drag and tined surfaces are common. Over-finishing the repair surface can weaken it and make it susceptible to scaling and durability problems. One airport that participated in this study installed the repair material slightly higher than the surrounding concrete and then ground the repair flush after it hardened, finding that this approach mitigates material settlement.

Curing is very important for PDR, since the ratio of the surface area to volume of the repair is typically large, and moisture can be rapidly lost through evaporation. Curing recommendations include the following (Frentress and Harrington 2012, Smith et al. 2014, USAF 2017):

- For cementitious materials, curing is often done by applying an ASTM C309 white-pigmented curing compound immediately after water from the surface has evaporated. Poly-alpha-methylstyrene (PAMS) resin curing compounds have been found to be highly effective.
- Curing material application rates are higher for PDRs than for full slabs or larger areas, usually 1½ to 2 times the normal application rate.
- Other effective curing methods include moist burlap or polyethylene sheeting. Insulating blankets can be used in cold weather conditions or to accelerate strength gain but should be used cautiously in warm weather conditions.

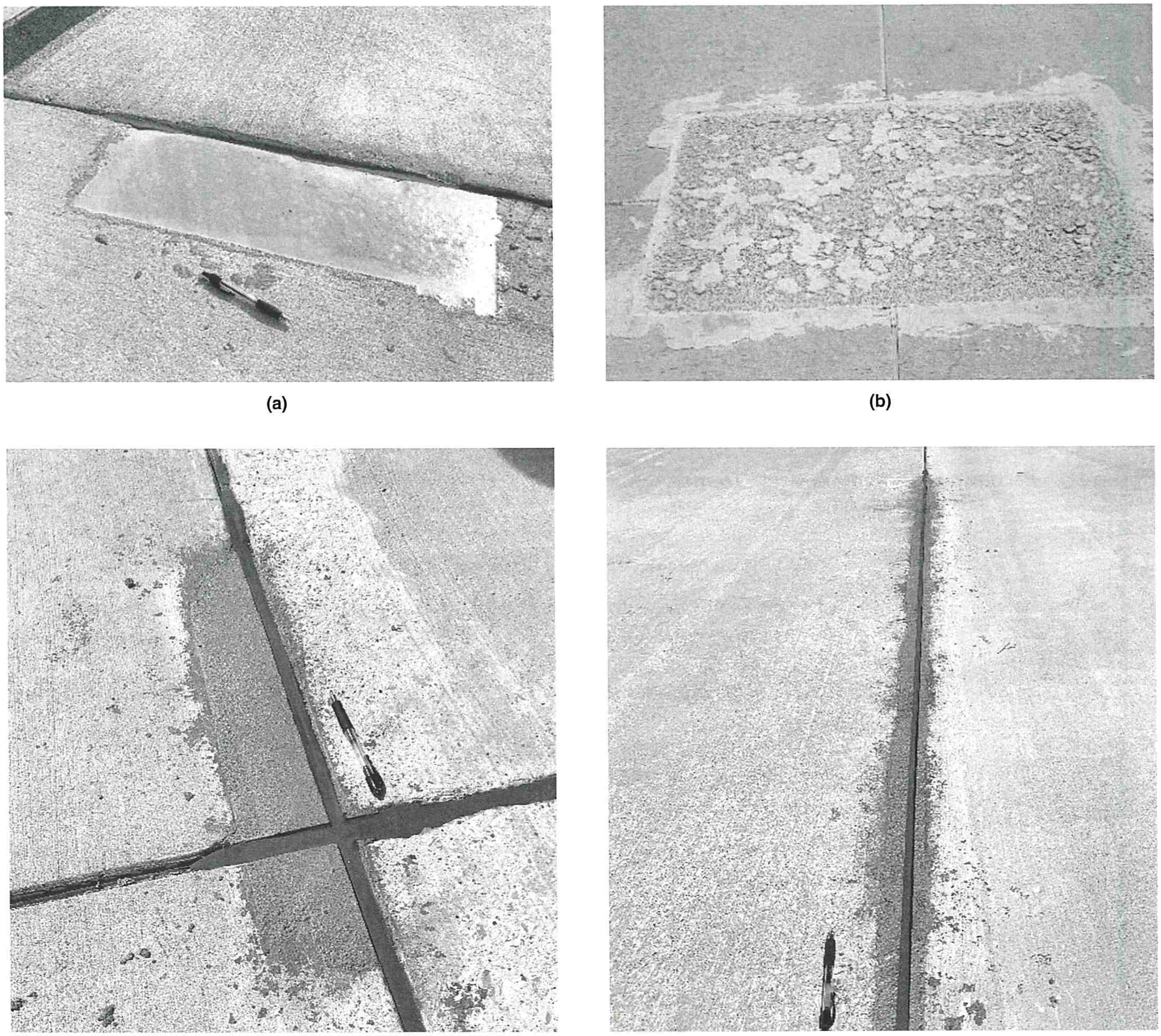
Some proprietary materials do not require curing. For these materials, the manufacturer's recommendations should be followed.

Joint Resealing

Following curing—if it was necessary to reestablish the joints—remove the joint/crack insert or reforming material at the surface so that the joint or crack can be properly prepared (i.e., cleaned). Then create the reservoir and place the appropriate joint/crack sealant.

Opening to Traffic

The new PDR must be protected from traffic until the material has achieved the required strength. The time to opening can vary considerably and depends on the PDR material used and other environmental factors. Portland cement–based materials may take days to gain sufficient strength, while some HES and proprietary materials may reach the required strength in a matter of minutes or hours. For cementitious materials, mix design testing can help establish strength gain properties (since field testing is not likely with the small batch quantities). Alternative methods for estimating strength gain (e.g., maturity meters) for PDRs have not been widely



(a) (b) (c) (d)

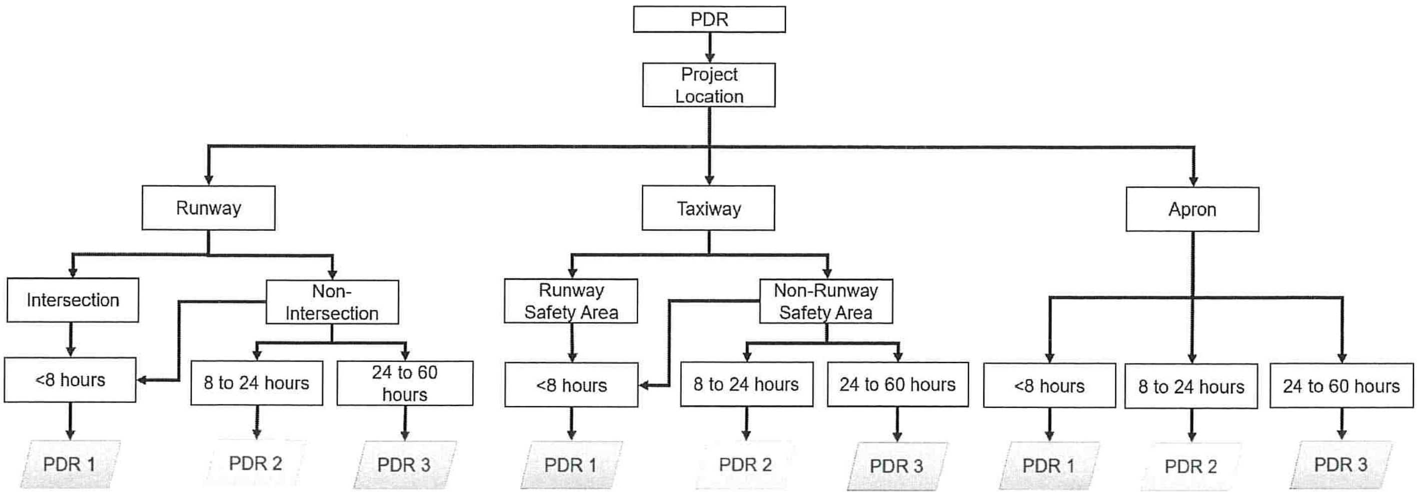
Note: See Figure 10 and Table 9 for explanation of the types of partial-depth repair.
Source: Nichols Consulting Engineers, Chtd.

Figure 16. Examples of completed partial-depth repairs: (a) Type 1 joint, (b) Type 1 joint that used a flexible repair material that did not require reestablishing of the joint, (c) Type 1 corner, and (d) Type 2 joint.

used. Manufacturers' recommendations for opening to traffic should be followed for proprietary materials. Figure 16 shows examples of completed PDRs.

Partial-Depth Repair Assessment Tool

Figure 17 and the associated tables (Tables 10–12) present a framework for assessing some of the key variables considered during planning for and constructing PDRs. This tool provides users with practical guidance on the feasibility of concrete pavement repair techniques for a variety of facilities and closure times.



Note: See Table 10, Table 11, and Table 12 for PDR 1, PDR 2, and PDR 3, respectively.
Source: Nichols Consulting Engineers, Chtd.

Figure 17. Partial-depth repair decision framework.

Figure 17 presents a decision tree for identifying the location of the planned PDR.

1. Select the facility on which the PDR will be completed (i.e., runway, taxiway, or apron).
2. Identify the relative operational priority of the repair area (e.g., runway intersection, runway safety area).
3. Determine how much time is available to do the work. Closure time is divided into three groups:
   - Less than 8 hours (equivalent to an overnight closure),
   - 8 to 24 hours (equivalent to a 1-day closure), and
   - 24 to 60 hours (equivalent to a weekend closure).

In many instances, work can be scaled to fit into the available closure time. That is, if a closure of less than 8 hours is the only available option for a given material and preparation method, the number of repairs may be limited in a given closure window to ensure all repair areas have achieved the required strength at the time of opening. Similarly, with a longer closure time, a more conventional repair material can be used. Longer closure times also permit a higher production rate, as more time is available to work under a single mobilization.

Each set of decisions leads to a table that summarizes the planning and construction considerations associated with the resulting box in Figure 17; see Table 10 for PDR 1, Table 11 for PDR 2, and Table 12 for PDR 3.

Table 10. Summary of PDR 1 decisions.

PDR 1 (<8 hours)	
Preparation	
Repair types and location	• Type 1: Spot repairs from 15 inches to 6 feet along the length of a joint. • Type 2: Extended-length repairs along a longitudinal or transverse joint or cracks longer than 6 feet. • Consider closure time and placement rate in selecting the quantity of repairs and ensure the final repair placed during closure will be able to achieve the required strength at the time of opening.
Material selection considerations	• Allowable closure time: VHES proprietary materials are likely needed, although some highly accelerated portland cement–based mixtures may be acceptable. • Minimum strength requirements. • Workability time. • Necessary batching equipment. • CTE. • Ambient temperature and climatic conditions. • Cost. • Material performance. • Size of the repair area.
Repair boundaries	• Extend at least 3 inches beyond unsound concrete on all sides of the repair. • Minimum repair length (along the joint) of 15 inches. • Minimum width (away from the joint) of 10 inches. • Minimum depth of 2 inches or according to manufacturer's recommendation. • Keep repair boundaries square or rectangular and avoid irregular shapes.
Demolition/Removal	
Removal method	• For Type 1: Saw and chip out. • For Type 2: Mill out. • Mill out will be faster than saw and chip out.
Cleanup	• Dry sweeping. • Light sandblasting. • Compressed air blasting. • High-pressure water.
Joint preparation	• Insert a polystyrene, polyethylene, or asphalt-impregnated fiberboard strip or other compressible joint-/crack-reforming material into the joint or working crack. Some proprietary flexible repair materials can be placed without reestablishment of the joint (check manufacturer's recommendations), but the joint or crack must still be taped or caulked to prevent infiltration. • Caulk can be used in the joint or crack to prevent infiltration of repair material.
Material Mixing and Placement	
Bonding agent	• For cementitious materials, a bonding agent is not required, but HES epoxy bonding agents have been used. • Follow manufacturer's recommendations for proprietary materials.
Mixing and placement	• Use a small drum or paddle-type mixer with a capacity of up to 2 cubic feet. • Follow the manufacturer's recommendations for proprietary materials. • Ensure proper consolidation.
Finishing	• A stiff board can be used for small repairs. • Work the material toward the perimeter of the repair. • For cementitious repair materials, place grout around the circumference of the repair and into any saw cut overruns. • Texture to match surrounding slab.

(continued on next page)

Table 10. (Continued).

PDR 1 (<8 hours)	
Curing	• Apply a white-pigmented curing compound for cementitious materials that meet ASTM C309. PAMS curing compounds have been found to be highly effective. • Follow the manufacturer's recommendations for proprietary materials.
Joint sealing	• Make sure transverse and longitudinal joints are well formed or sawed. • Ensure joints are clean and dry. • Install approved sealant in joint (and in overruns if not previously filled with grout). Note: Resealing is often performed in a separate closure in compliance with the sealant manufacturer's recommendations.
Opening to Traffic	
Compressive strength	• Demonstrated as part of mix design, typically 3,100 psi. Note: Some VHES polymeric materials cannot be tested by using compressive strength, and a time-based opening criterion is used according to the manufacturer's recommendations.
Flexural strength	• Flexural strength is rarely specified for PDR materials.
Other	• Timing per manufacturer's recommendations. • Maturity monitoring. • Consider whether direct traffic loadings will be likely (i.e., only require strength for an emergency loading as opposed to continuous traffic).

Note: psi = pounds per square inch.

Table 11. Summary of PDR 2 decisions.

PDR 2 (8–24 hours)	
Preparation	
Repair types and location	• Type 1: Spot repairs from 15 inches to 6 feet along the length of a joint. • Type 2: Extended-length repairs along a longitudinal or transverse joint or cracks longer than 6 feet. • Consider closure time and placement rate in selecting the quantity of repairs and ensure that the final repair placed during the closure will be able to achieve the required strength at the time of opening.
Material selection considerations	• Allowable closure time: accelerated portland cement–based mixtures may work, but consider proprietary materials. • Minimum strength requirements. • Workability time. • Necessary batching equipment. • CTE. • Ambient temperature and climatic conditions. • Cost. • Material performance. • Size of the repair area.
Repair boundaries	• Extend 3 inches beyond unsound concrete on all sides of the repair. • Minimum repair length (along the joint) of 15 inches. • Minimum width (away from the joint) of 10 inches. • Minimum depth of 2 inches (or according to the manufacturer's recommendation). • Keep repair boundaries square or rectangular and avoid irregular shapes. • Avoid saw cut overrun.

Table 11. (Continued).

PDR 2 (8–24 hours)	
Demolition/Removal	
Removal method	• Type 1: Saw and chip out. • Type 2: Mill out. • Mill out will be faster than saw and chip out.
Cleanup	• Dry sweeping. • Light sandblasting. • Compressed air blasting. • High-pressure water.
Joint preparation	• Insert a polystyrene, polyethylene, or asphalt-impregnated fiberboard strip or other compressible joint-/crack-reforming material into the joint or working crack. Some proprietary flexible repair materials can be placed without reestablishment of the joint (check manufacturer's recommendations), but the joint or crack must still be taped or caulked to prevent infiltration. • Caulk can be used in the joint or crack to prevent infiltration of repair material.
Material Mixing and Placement	
Bonding agent	• For portland cement concrete materials, a bonding agent is not required. A grout made with cement and water (and at times sand) has been used. • Follow the manufacturer's recommendations for proprietary materials.
Mixing and placement	• Use a small drum or paddle-type mixer with a capacity of up to 2 cubic feet. • Follow the manufacturer's recommendations for proprietary materials. • Ensure proper consolidation.
Finishing	• A stiff board can be used for small repairs. • Work the material toward the perimeter of the repair. • Place grout around the circumference of the repair and into any saw cut overruns. • Texture to match surrounding slab.
Curing	• Apply a white-pigmented curing compound for cementitious materials that meet ASTM C309. PAMS curing compounds have been found to be highly effective. • Follow the manufacturer's recommendations for proprietary materials.
Joint sealing	• Make sure transverse and longitudinal joints are well formed or sawed. • Ensure joints are clean and dry. • Install approved sealant in joint (and in overruns if not previously filled with grout). Note: Resealing is often performed in a separate closure in compliance with the sealant manufacturer's recommendations.
Opening to Traffic	
Compressive strength	• Demonstrated as part of mix design, typically 3,100 psi. Note: Some HES polymeric materials cannot be tested by using compressive strength, and a time-based opening criterion is used according to the manufacturer's recommendations.
Flexural strength	• Flexural strength is rarely specified for PDR materials.
Other	• Timing per manufacturer's recommendations. • Maturity monitoring. • Consider whether direct traffic loadings will be likely (i.e., only require strength for an emergency loading as opposed to continuous traffic).

Table 12. Summary of PDR 3 decisions.

PDR 3 (24–60 hours)	
Preparation	
Repair types and location	• Type 1: Spot repairs from 15 inches to 6 feet along the length of a joint. • Type 2: Extended-length repairs along a longitudinal or transverse joint or cracks longer than 6 feet. • Consider closure time and placement rate in selecting the quantity of repairs and ensure that the final repair placed during the closure will be able to achieve the required strength at the time of opening.
Material selection considerations	• Allowable closure time: Lightly accelerated portland cement–based concrete mixtures are suitable. • Minimum strength requirements. • Workability time. • Necessary batching equipment. • CTE. • Ambient temperature and climatic conditions. • Cost. • Material performance. • Size of the repair area.
Repair boundaries	• Extend 3 inches beyond unsound concrete on all sides of the repair. • Minimum repair length (along the joint) of 15 inches. • Minimum width (away from the joint) of 10 inches. • Minimum depth of 2 inches, or according to the manufacturer's recommendations. • Keep repair boundaries square or rectangular and avoid any irregular shapes. • Avoid saw cut overrun.
Demolition/Removal	
Removal method	• Type 1: Saw and chip out. • Type 2: Mill out. • Mill out will be faster than saw and chip out.
Cleanup	• Dry sweeping. • Light sandblasting. • Compressed air blasting. • High-pressure water.
Joint preparation	• Insert a polystyrene, polyethylene, or asphalt-impregnated fiberboard strip or other compressible joint-/crack-reforming material into the joint or working crack. Some proprietary flexible repair materials can be placed without reestablishing the joint (check manufacturer's recommendations), but the joint or crack must still be taped or caulked to prevent infiltration. • Some proprietary flexible repair materials can be placed across a joint (check manufacturer's recommendations).
Material Mixing and Placement	
Bonding agent	• For portland cement concrete materials, a bonding agent is not required. A grout made with cement and water (and at times sand) has been used by some. • Follow the manufacturer's recommendations for proprietary materials.
Mixing and placement	• Use a small drum or paddle-type mixer with a capacity of up to 2 cubic feet. • Follow the manufacturer's recommendations for proprietary materials. • Ensure proper consolidation.
Finishing	• A stiff board can be used for small repairs. • Work the material toward the perimeter of the repair. • Place grout around the circumference of the repair and into any saw cut overruns. • Texture to match surrounding slab.

Table 12. (Continued).

PDR 3 (24–60 hours)	
Curing	• Apply a white-pigmented curing compound for cementitious materials that meet ASTM C309. PAMS curing compounds have been found to be highly effective. • Follow the manufacturer's recommendations for proprietary materials.
Joint sealing	• Make sure transverse and longitudinal joints are well formed or sawed. • Ensure joints are clean and dry. • Install approved sealant in the joint (and in overruns if not previously filled with grout). Note: Resealing is often performed in a separate closure in compliance with the sealant manufacturer's recommendations.
Opening to Traffic	
Compressive strength	• Typically 3,100 psi.
Flexural strength	• Flexural strength is rarely specified for PDR materials.
Other	• Timing per manufacturer's recommendations. • Maturity monitoring.

CHAPTER 4

Full-Depth Repair

As defined in Chapter 1, FDR refers to full-depth removal and replacement of a portion of a slab or an entire slab by using either cast-in-place concrete or precast concrete. This chapter discusses the appropriate distresses, materials, design, and construction for an FDR project and presents an assessment tool to help users evaluate the considerations necessary to complete a successful FDR.

Introduction to Full-Depth Repair

FAA AC 150/5380-6C (FAA 2014b) identifies the following FDR types, which are based on how much of the slab is being repaired:

- Partial-width, partial-slab repair (e.g., a corner break),
- Full-width, partial-slab replacement (e.g., a deteriorated joint), and
- Full-slab replacement (e.g., high-severity midslab cracking or shattered slab condition).

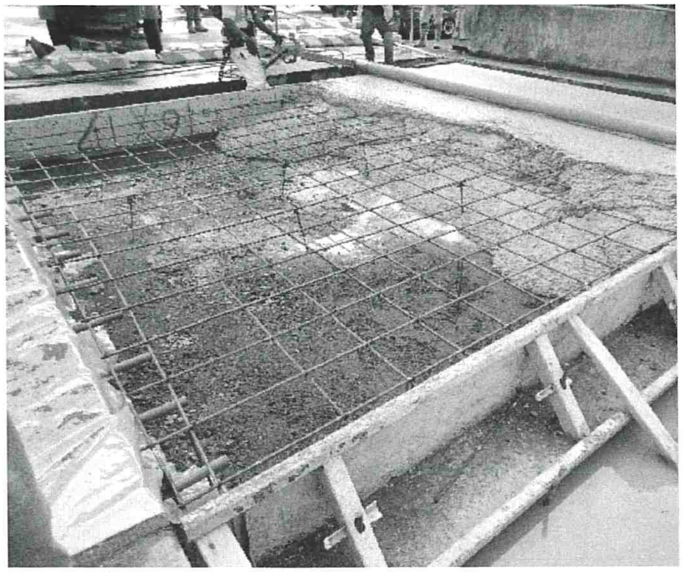
For discussion, partial- and full-slab FDRs are grouped together. FDRs are typically either cast-in-place concrete or precast concrete slabs with deterioration extending through more than one-half the thickness of the existing concrete pavement. Precast slabs are generally used for full-slab replacements on airfields, either as an intermediate step when cast-in-place repairs are being made or as the final pavement. Figure 18 provides examples of installations of cast-in-place and precast FDRs.

Cast-in-place FDR is the most common method reported by the airports that participated in this study. Table 13 lists advantages and disadvantages of this technique.

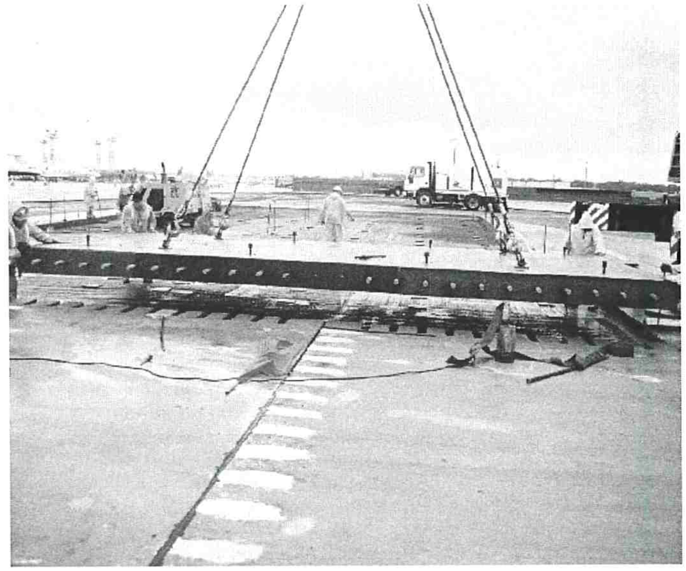
Precast slab FDR is an alternative repair method that was used as early as the 1930s on highways and airfields for partial- or full-slab replacement, although widespread implementation of this method at that time was limited (Priddy et al. 2013). Interest in the use of precast concrete has increased at airports, especially in areas where very short closures are necessary (e.g., runway intersections). According to Tayabji et al. (2009), the main justifications for the use of precast concrete slabs are time savings or reduced closure times; otherwise, precast concrete pavement is typically not economically competitive. Table 14 lists advantages and disadvantages of precast slabs.

Following are key considerations for determining the feasibility of precast slabs as an FDR option:

- Extent and location of the damaged pavement;
- Temporary or permanent repair;
- Expected performance and life of the repair;



(a)



(b)

Source: (a) Nichols Consulting Engineers, Chtd., and (b) Shiraz Tayabji.

Figure 18. Examples of cast-in-place and precast full-depth repairs: (a) cast-in-place and (b) precast.

Table 13. Advantages and disadvantages of using cast-in-place concrete for full-depth repair.

Advantages	Disadvantages
• Familiarity of contractors with the equipment and process. • Proven technique for a range of distresses.	• Difficulty in placement during certain adverse weather conditions. • Durability issues with some materials. • Curing time.

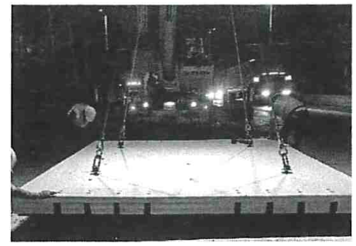
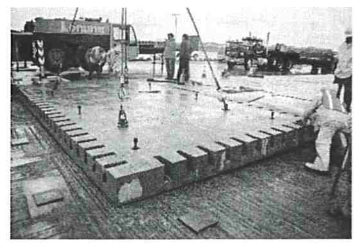
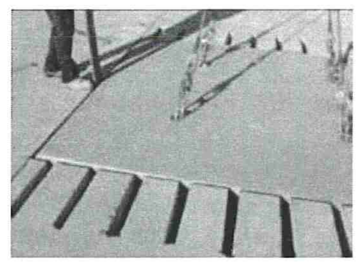
Source: Williams et al. (2012), Priddy et al. (2013).

Table 14. Advantages and disadvantages of precast slab concrete for full-depth repair.

Advantages	Disadvantages
• No on-site concrete curing time. • Conventional concrete can be used. • Quality of concrete is higher. • Can be prefabricated and stored. • Fabricated under controlled conditions. • Weather window for installation is broad.	• Cost is much higher. • Moving and placing large panels may be difficult. • Slab edges and dowel bars may get damaged. • Experienced crews are required. • Crane height may penetrate FAA Federal Aviation Regulation (FAR) Part 77 surfaces and require closure of adjacent runways.

Source: Buch et al. (2003), Olidis et al. (2010), Ashtiani et al. (2010), Priddy et al. (2013), Tayabji et al. (2012), and Chao (2018).

Table 15. Examples of precast slab installations for airfields.

Panel Type	Description	Image[a]
Bottom dowel slots	Precast slabs with bottom slots in the transverse joint faces of the slab to give room for the load-transfer dowel bars. Screws are used to adjust the final slab elevation, and grout is injected underneath the slab. This method can be used for single or multiple connected panel repairs.	
Top dowel slots	Precast slabs with top slots in the transverse joint faces of the slab to give room for the load-transfer dowel bars. Screw-type leveling pads are used to adjust final slab elevation, and grout is injected underneath the slab. This method can be used for single or multiple connected panel repairs.	
ERDC[b] standard panel	Consists of a standard panel with dowel bars at the middepth along both transverse edges and a second, or "terminal," panel that has dowels in only one of the edges, while the other transverse edge has dowel receptacles for connecting it to a standard panel. The system uses a flowable fill or foam injection as a leveling course and to provide uniform support.	

[a]Row 1: Nichols Consulting Engineers, Chtd.; Row 2: Shiraz Tayabji; Row 3: Ashtiani et al. 2010.
[b]Priddy et al. (2013).

- Existing pavement structure;
- Feasibility of transporting and placing large, heavy panels or ability to manufacture panels on or near site and place them; and
- Local availability of experienced contractors and precast yards.

A more detailed description of precast slab repair methods is found elsewhere (Olidis et al. 2010, Ashtiani et al. 2010, Priddy et al. 2013, Smith and Snyder 2019). Given the complexity of these systems, they require independent engineering analysis and design for each project. Table 15 presents a few examples of precast installations that have been used for airfield pavements.

Candidate Distresses and Conditions

FDR is warranted when other methods (e.g., PDR, diamond grinding) can no longer be used to repair distresses effectively. In most cases, the distresses have severely diminished the structural integrity (i.e., load-carrying capacity) of the slab. The following pavement distresses are considered candidates for FDR [American Concrete Pavement Association (ACPA) 1995, Smith et al. 2014, FAA 2014b, and U.S. DOD 2018]:

- Corner breaks (low, medium, and high severity);
- Blowups;

- Transverse and longitudinal cracking (medium to high severity) or shattered slabs;
- High-severity spalling or exposure of dowel bars;
- Severe joint deterioration that is not a candidate for PDR;
- Deterioration of existing repairs or adjacent to existing repairs (medium to high severity);
- Deteriorated utility cuts or can lights; and
- Materials-related distresses, such as alkali–silica reactivity, or medium- and high-severity D-cracking (as a stopgap measure).

Figure 19 illustrates some of the common distresses that are candidates for FDR. Note that FDR may only provide a temporary solution when severe materials-related distresses (e.g., alkali–silica reactivity) or freeze–thaw distresses (e.g., D-cracking) are widespread. In these cases, FDR can be used to replace slab areas that pose a safety or operational hazard to aircraft in anticipation of a future, larger rehabilitation project. Concrete pavements exhibiting severe structural deterioration over an entire project or facility may be better suited for structural overlay or reconstruction.

Material Selection

Material selection requirements vary somewhat between cast-in-place and precast FDRs, as described below.

Cast-in-Place Repairs

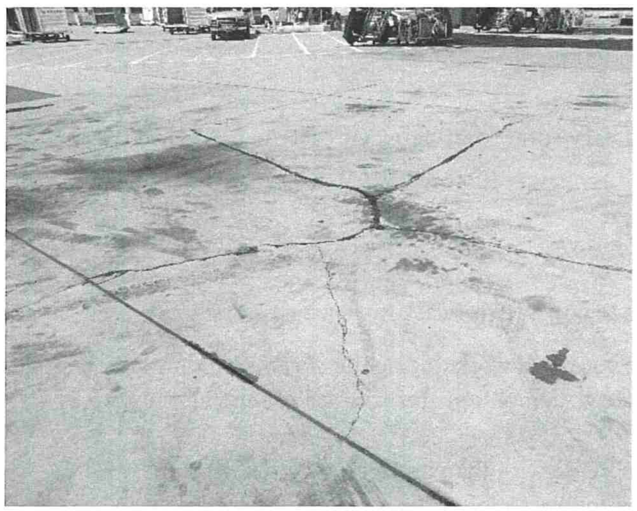
Following are some of the factors to consider for cast-in-place materials:

- Material strength gain required to complete work during the closure window after completion of other required FDR work items (e.g., demolition and removal of concrete, grade preparation, placing concrete).
- Material costs, which generally increase with increased rate of strength gain.
- Effect on unit repair costs of FDR repair size and project size (number of slabs to be replaced), larger repairs and larger projects typically being more cost-effective. Repair size can also affect the time required to complete each repair, in turn affecting productivity during short work windows.
- Effect of the temperature and weather conditions anticipated during placement and curing on the selection of the repair material. General climate conditions, such as freeze–thaw cycling, can rule out the use of some aggregates and other materials.
- Trade-offs between physical and mechanical properties of different repair materials (e.g., increases in early strength may correspond with increased shrinkage and reduced durability).
- Experience working with the material.
- Material performance (historical or as reported by other users).

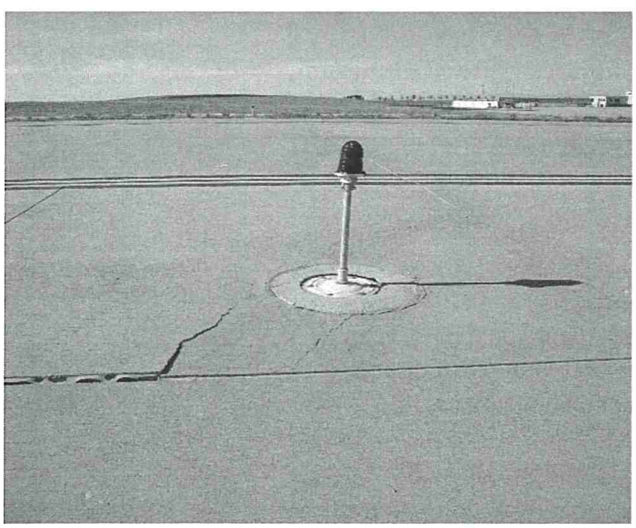
FAA AC 150/5380-6C (FAA 2014b) discusses the use of P-501 cement concrete pavement or state DOT materials for FDR. The P-501 specification states that state DOT materials are allowable for use on pavements for aircraft weighting less than 60,000 pounds. The U.S. DOD *O&M Manual* (2018) also indicates conventional concrete (ASTM C150 Portland Cement Type I–based mixes) are typically used but also discusses the use of ASTM C150 Portland Cement Type III–based mixes and proprietary materials for early opening to traffic requirements.

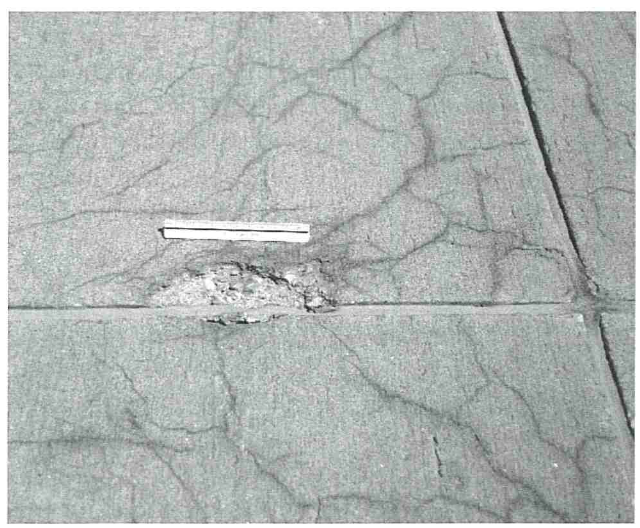
The allowable closure time is often a driving factor in the selection of materials for cast-in-place repairs. In general, it is better to use the least exotic material that meets opening-to-traffic requirements. A conventional ASTM C150 Type I cement mix could take several days to

(a) (b)



(c)





(d) (e)

Source: Nichols Consulting Engineers, Chtd.

Figure 19. Candidate distresses for full-depth repair: (a) corner breaks, (b) cracking (transverse or longitudinal), (c) shattered slab, (d) damage from alkali–silica reactivity (stopgap repair), and (e) widespread D-cracking (stopgap repair).

achieve adequate strength for opening to traffic. Concrete featuring either ASTM C150 Portland Cement Type I or Portland Cement Type III is commonly used with other mix design modifications and can produce mixtures that are suitable for opening to traffic in as little as 6 to 8 hours. For earlier opening times, ESC mixtures using calcium aluminate or CSA cements can be used to meet strength requirements in as little as 2 to 4 hours (Priddy 2015).

To achieve early strength gain in conventional concrete mixtures, the use of chemical admixtures is common. These include accelerators and normal-range and high-range water-reducing admixtures. Note that calcium chloride or admixtures containing calcium chloride, as well as high-range water-reducing admixtures, are not permitted under Item P-501 "Cement Concrete Pavement," in FAA AC 150/5370-10H, *Standard Specifications for Construction of Airports* (FAA 2018).

Examples of the range in mixture proportions for different time-to-opening requirements are summarized in Table 16.

Because ESC mixes typically contain higher cement contents and multiple admixtures, it is not uncommon for them to experience increased shrinkage, altered microstructure, and unexpected interactions (Van Dam et al. 2005). As a result, the long-term durability of these mixtures is potentially at risk.

Several proprietary VHES cements (ASTM C1600) are commercially available. These specialty cements (e.g., CSA) can provide VHES to meet short time-to-opening time frames (<4 hours). Rapid-strength cements are typically more costly and can pose a challenge in handling and placing. These materials can be very sensitive to the weather conditions during installation and curing. For a new project—even if the construction crews have experience working with these materials—personnel should demonstrate their ability to properly install the materials off-site or should start work on the least-critical areas (e.g., aprons) before moving to critical areas (e.g., runways).

Precast Slabs

The most common material for precast slabs is conventional or accelerated portland cement concrete. Usually, the design strength requirements are the same as those for the existing concrete pavement, although early strength is often accelerated to facilitate stripping of forms. Conventional concrete is typically used because the slabs are produced before being hauled to the installation site. Precast slabs are also typically reinforced with deformed bars to control cracking that may occur during transport and handling and can be prestressed to reduce load-related stresses and associated cracking.

Table 16. Typical constituent materials proportions for portland cement–based early-strength concrete mixtures.

	Proportion, by Time to Opening		
Mixture Parameter	**4–6 h**	**6–8 h**	**20–24 h**
Cement type	I or III	I or III	I or III
Cement content (lb/yd^3)	650–895	715–885	675–800
w/cm ratio	0.38–0.40	0.36–0.40	0.40–0.43
Accelerator	Yes	Yes	Yes or No

Note: w/cm = water to cement.
Source: Smith et al. (2014).

Design

The design process for FDR can vary in terms of the extent and nature of the repair (i.e., one slab versus multiple slabs, emergency versus nonemergency use). In some cases, standard details may be sufficient (e.g., emergency replacement of one slab) whereas specific plans and specifications may be necessary for larger projects. With FDR, alternative designs should also be considered and evaluated with respect to the need for accelerated construction (i.e., repairs to an apron pavement may be performed over a longer closure than repairs to a taxiway or runway). It is important to understand the existing pavement conditions as well as the extent of repairs to appropriately plan FDR.

Cast-in-Place Repairs

Design considerations, particularly for larger cast-in-place FDR projects, include the following:

- **Material requirements:** Conventional materials can be used [FAA AC 150/5380-6C (FAA 2014b) references P-501 cement concrete pavement or state DOT materials], with the time allowed for strength gain being the major consideration. High-cement-content accelerated conventional mixes with a low w/cm ratio can achieve strengths relatively quickly but may exhibit shrinkage and early-age cracking. Proprietary materials can achieve strengths very quickly with use based on the manufacturer's recommendations. Contractor experience is very important when unconventional materials are being used.
- **Provisions for incentives/disincentives when repairs have an impact on critical airport operations:** Provide monetary incentives for early completion. Penalties for not returning pavement to service are generally much more severe for runways (e.g., $500/minute) but can be applied to other areas if they are critical to airport operations.
- **QC/QA:** QC/QA for FDR procedures often follows standard specifications [such as P-501 cement concrete pavement (FAA 2018)] because quantities are greater (and, therefore, more controllable) than for typical PDR projects. Onsite inspectors and material testing technicians must be trained or have experience preparing beam specimens with VHES, if used. Additional test specimens or alternative strength measurement tests (such as maturity meters) need to be considered if short closure time frames are involved.
- **Opening-to-traffic requirements:** Opening to traffic should be based on strength gain. The time allowed to achieve the required strength will depend on the allowable closure (e.g., strength needs to be achieved in less than 4 hours or in 24 hours or more). Some materials may set so quickly that time can be an indicator, but strength should ultimately be verified. Environmental conditions (e.g., temperature, humidity) may affect or alter the rate of strength gain.
- **Provision for a preconstruction conference:** It is advisable to hold a preconstruction meeting prior to closing pavement areas and allowing construction work to proceed. Establishing work methods and personnel responsibilities is significant to the success of FDR projects, and just-in-time training is extremely useful, especially when proprietary materials are being used. Construction of a repair demonstration (or test strip) on a noncritical pavement area (or off-site) is also suggested, particularly when new concrete materials or ESC are being used. Contractor experience (beyond experience with the materials) is also important when trying to coordinate and carry out rapid FDR projects in an area of aircraft operations.
- **Slab size requirements:** For corner breaks and partial-slab repairs, FAA AC 150/5380-6C (FAA 2014b) indicates saw cuts be made at least 2 feet beyond the observed limits of damage. The U.S. DOD *O&M Manual* (2018) indicates that saw cuts should be a minimum of 3 feet from a joint. If the slab width is less than 20 feet, or if there are full-depth cracks within the interior area of the slab, full-width slab repair is required. The manual also indicates 10 feet

as the minimum repair dimension for airfield applications, to avoid rocking and pumping of the repair.

- **Joint considerations (doweling and tying):** Load transfer needs to be provided at joints within large FDR areas and to reestablish joints with adjacent pavement. Load-transfer type (typically dowel or tie bar), size, and location need to be included. Details for installation—particularly drilling, alignment, and grouting—also need to be included.

The planning and design process needs to consider what-ifs and develop appropriate contingencies. While not an exhaustive list, the following things should be considered:

- **Backup equipment and alternative sources of material production:** All airports interviewed indicated the need for backup equipment and materials so that production facilities can avoid potential delays (or even not finishing the work within the required closure) due to equipment breakdown. Having backup supplies (e.g., dowel bars, PDR material) is also useful in the case of damage to adjacent concrete slabs or if the need to address unknown conditions (i.e., extend repair into an adjacent slab) arises.
- **Weather monitoring and mitigation:** Ideally, FDR work should be scheduled during periods with historically acceptable weather for concrete placement. One agency interviewed had sufficient canopies to erect over the repair so work could continue during rain, if necessary. This is less of an issue for precast FDRs.
- **Alternate methods of reestablishing pavement surface:** Some airports use precast slabs as temporary (or emergency) pavement if repair cannot be completed during a single shift. Alternate materials (such as asphalt) may also be considered.

In addition:

- **Determine how utilities will be addressed:** One survey respondent kept its in-pavement lights by coring around them. The concrete was then chipped off the cans and new concrete placed around the existing cans. Backup supplies can also be useful in case of damage to utilities or unknown conditions.
- **Plan site access and movement across the airfield well in advance:** Haul time can become a significant factor, especially with ESC.

Precast Slabs

Many of the design items discussed for cast-in-place FDR also apply to precast slab FDR. Following are some of the differences:

- Precast slab FDR is mainly used for full-slab replacement on airfields, but joint replacements are possible as well. Slabs are typically fabricated to produce approximately half-inch gaps around the entire panel to facilitate installation. Slab thickness is typically 0.5 to 1 inch less than the pavement being replaced; this allows for minor variations in slab thickness and base elevation while providing a gap for installing fine aggregate, grout, or urethane bedding material. Before fabrication and installation, the existing pavement thickness should be verified by coring or nondestructive means [e.g., ground-penetrating radar (GPR)] to avoid construction surprises.
- Typically, specially proportioned mixtures that use ordinary portland cement are used for precast slabs. Early strength requirements are driven by the need to remove and reuse forms for the next cast, typically in less than 24 hours. Precast concrete strength at installation is typically 5,000–6,000 pounds per square inch (psi)—far above typical design strength requirements.
- Load-transfer is typically provided by dowels and tie bars, as required for the specific installation. For connections with existing adjacent panels, the dowels and tie bars are typically drilled

and anchored in the existing slabs, and the precast slabs (fabricated with bottom slots or full-depth slots) are "dropped in" over the bars. Connections between multiple new precast slabs can involve slots in one panel and embedded dowels in the other. Alternatively, plain panels can be installed and dowels can be retrofit into slots cut across the joints with adjacent panels. Smith and Snyder (2019) provide details concerning precast dowel load-transfer systems. Panel reinforcement and embedment (e.g., lift-pins) needs to be designed appropriately.

- Precast slab reinforcement and embedment (e.g., lift-pins, embedded jacks, grout ports, slot formers, etc.) needs to be designed appropriately.
- Addressing in-pavement lighting (or other utilities) requires additional planning to ensure proper lighting alignment after installation. Note that lighting alignment will depend on both the installation of the can in the panel and on the proper elevation and rotation of the panel at installation. One project included in this study used two-piece cans and developed a solution for connecting the two pieces after panel placement. Another used adjustable light cans.
- Establishment of haul routes and site access must consider the ability to transport slabs from the fabrication area to the repair site, including the maximum width permitted along the transport route. Full-sized airfield panels typically cannot be transported over roads, so other transport and/or fabrication options must be considered.
- Backup equipment should include lifting cranes (or other equipment) needed to place the precast slabs. The impact of crane height to adjacent runway operation must be considered.

Construction

The generalized FDR construction procedure for cast-in-place includes (Hajek et al. 2011, Smith et al. 2014, FAA 2014b, U.S. DOD 2018):

1. Select repair location and mark boundaries.
2. Saw the repair boundaries and remove the damaged concrete without damaging the adjacent slabs to remain. Typically, 2 closely spaced parallel saw cuts are used at each boundary to minimize the chance of damaging the remaining concrete.
3. Restore the base, subgrade, and subdrains.
4. Restore the load-transfer system across the joints.
5. Replace any reinforcement.
6. Restore any expansion joints.
7. Place the new concrete.
8. Finish and texture to match the existing concrete.
9. Cure the concrete using the appropriate method.
10. Optional: perform diamond grinding.
11. Seal joints.
12. Open to traffic after proper curing.

Preparation for precast FDR is quite similar through the removal steps. The following are general guidelines for precast concrete slab construction (Tayabji et al. 2009, Smith and Snyder 2019):

1. Determine the dimensions of the repaired area; this dictates the necessary panel size. This might not be possible for some larger repair areas (such as 25-foot by 25-foot slabs) due to limitations in transporting and placing such large, heavy precast slabs. Use of large cranes to place large precast slabs may also have limitations due to FAR Part 77 requirements.
2. Verify the existing concrete pavement thickness. It is suggested that the precast slab be 0.5 to 1.0 inch thinner than existing concrete to allow for variations in the thickness of the existing pavement/elevation of the base and to allow room for leveling.

3. Install saw cuts parallel and perpendicular to the center line; care must be taken to ensure panel fit. Typically, 2 closely spaced parallel cuts are made per boundary.
4. Place bedding materials according to precast system requirements.
5. Install load-transfer mechanisms as designed for the project.
6. Provide an expansion cap at one end of each dowel. This step is not done if slab gaps are filled with structural grout as is done in many applications.
7. Control dowel alignment with proper installation and cages. The use of narrow slots makes panel installation more difficult.
8. If possible, multitask during the installation process to reduce construction time.
9. If necessary, after installation, grind the surface to ensure a smooth ride. Seal transverse and longitudinal joints.

Boundary Selection and Marking

Selection of repair boundaries for airfield FDR typically includes the following considerations (Hajek et al. 2011, Smith et al. 2014, U.S. DOD 2018):

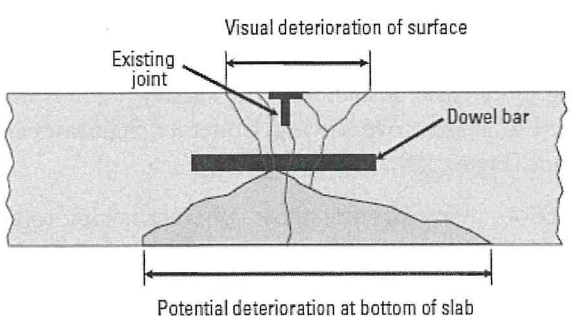
- Full-width slab replacement is required if the original slab width is less than 20 feet.
- Boundaries should encompass all deteriorated concrete and deteriorated subsurface layers.
- It is not unusual for deterioration at the bottom of the slab to extend beyond what is visible on the surface, especially near the joints (Figure 20). The limits of deterioration can be determined by representative coring or nondestructive testing (e.g., ground-penetrating radar).

Repair boundaries should be marked in advance in highly visible marking paint, as shown in Figure 21.

Concrete Demolition and Removal

Removal of the existing pavement can be very time-consuming. There are basically two methods for removal: the lift-out method and breakup-and-clean-out method.

- **Lift-out method:** The lift-out method is usually faster and less damaging to the subbase, and is advisable whenever possible. Slabs are cut into manageably sized pieces to facilitate removal. Holes are drilled into the slab pieces and lift-pins inserted. Then the slab pieces are lifted out and placed on a truck by means of a crane or other construction equipment with steel chains connected to the lift-pins. An alternate lifting method is to use a vacuum-based slab lifter. To minimize damage to the adjacent slabs during lift-out operations, additional saw cuts can be made a few inches from and parallel to the repair boundaries and the wedges



Source: Smith et al. (2014).

Figure 20. Visual pavement deterioration at top and potential damage to the bottom.

Source: Nichols Consulting Engineers, Chtd.

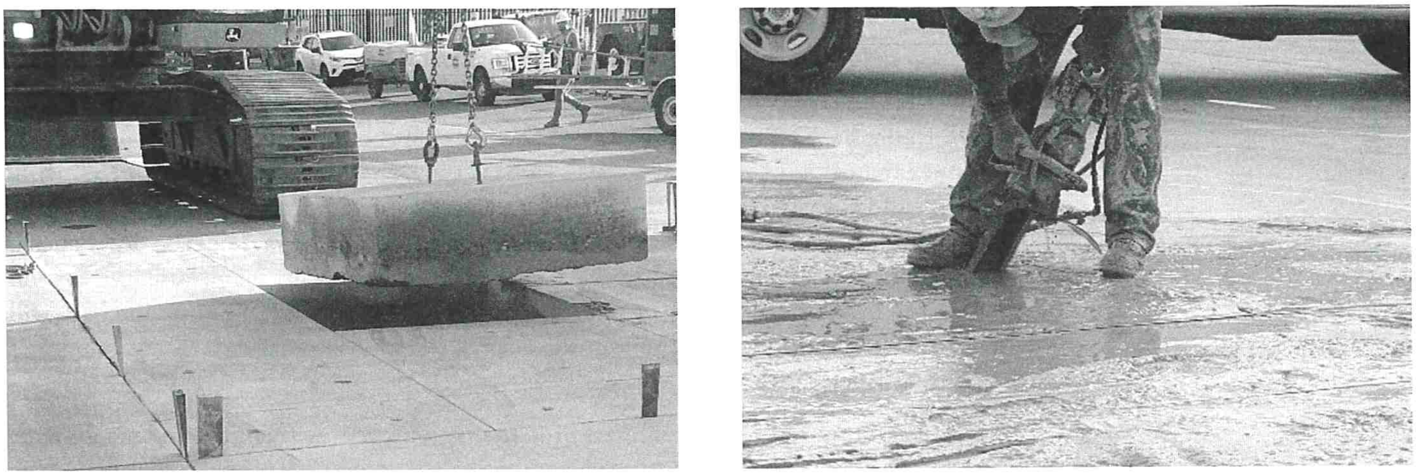
Figure 21. Example of marked full-depth repair boundaries.

of concrete removed to provide additional clearance during slab removal. This method is suggested when damage to adjacent slabs and subbase must be avoided. Wood shims can be wedged into saw cuts to minimize any rocking and potential spalling of adjacent pavement during removal.

- **Breakup-and-clean-out method:** The breakup-and-clean-out method uses concrete breaking equipment (typically jackhammers) to completely break the concrete into smaller, manageable pieces. This method should be avoided for slab replacements because it can damage adjacent slabs and results in disturbance to the base. However, this method must often be used when joints or slabs are so severely deteriorated that the lift-out method cannot be used. Furthermore, this method is used when damage to the base is not a critical concern or if only a few slabs are being repaired.

Most of the airports contacted for this study have used the lift-out method with established sawing procedures (Figure 22). Sawing is often performed by using a set pattern that provides a narrower band around the perimeter to minimize the risk of damaging the adjacent pavement. Some agencies specify the use of angled interior cuts to facilitate removal. Most feel that overruns during sawing should also be avoided. One agency requires that a piece of steel plate be placed along the joint to prevent oversawing. Concrete chainsaws are a possible option in corners to avoid overruns (Figure 22).

To expedite construction, many airports allow concrete sawing to be performed during a separate closure ahead of the closure for the pavement removal and replacement. The saw cut pattern is adjusted to avoid saw cuts near cracks, so as to avoid the creation of potential generators of FOD. An important step in allowing saw cutting to occur during an earlier closure is to have the pavement cleaned of sawing slurry prior to reopening. One airport turns to both in-house maintenance and ARFF personnel to help with saw slurry cleanup when needed, as they can quickly mobilize equipment when there is an urgent need.



(a) (b)

Source: (a) Nichols Consulting Engineers, Chtd., and (b) Applied Pavement Technology, Inc.

Figure 22. Concrete demolition and removal: (a) lift-out method (wood shims are installed at slab edges to minimize damage to adjacent slabs) and (b) concrete chainsaw used to minimize saw cut overrun.

With the lift-out method, stabilized base material may be bound to the bottom of the pavement slab. One airport found that applying a dynamic load (not sufficient to break the pavement) could break the bond during removal.

All demolition debris needs to be removed prior to continuation of grade preparation.

Site Preparation

Cast-in-Place Repairs

If removal of the distressed pavement damages the base, it may be necessary to add new material that must be graded and compacted (Van Dam et al. 2005). As determined by the project engineer, if the repair area is too wet, it should be properly dried (ACPA 1995, Smith at al. 2014, U.S. DOD 2018). In some cases, extremely weak subgrade may need to be remediated. Loose base material must be removed prior to placement of the repair material, as long-term performance is dependent on the soundness or stability of the existing base or subgrade material.

An alternative to using conventional backfill material is the use of flowable fill material (Smith et al. 2014). Flowable fill materials are easily placed; can be readily removed later, if needed; do not need to be compacted; and have sufficient compressive strength to provide acceptable support to prevent settlement. Flowable fill material is typically composed of portland cement, fly ash, 0.5-inch coarse aggregate, fine aggregate, and water.

Means to trim the base (or subgrade) need to be available in the event the base is found to be too high (>1 inch). Different equipment, including a small milling machine or excavator, can be utilized, depending on the geometry of the repair and type of base material. Layer thickness tolerances in the FAA P-501 specification (FAA 2018) should be considered for assessing the need to trim the base prior to placing concrete.

In the case of drainable bases, minor damage (e.g., <10% of the area) could be repaired with nondrainable material. If there is significant damage to a drainable base, similar material should be used for the repair.

Precast Slabs

For precast FDR, base preparation is generally dependent on the system or supplier being used. The same care for base repair and trimming necessary for cast-in-place repairs should be applied to the base for precast slabs. The thickness of the precast slab is often designed to be thinner than that of the existing slab (unless the slab will be ground flush following installation), and the gap between the base and the slab bottom must be filled with bedding material. Common bedding materials used to fill the gap between the leveled base and flat slab bottom include a thin layer of sand, flowable fill, grout, or polyurethane foam. Base preparation for precast slab FDR is much more critical than for cast-in-place FDR, because the base will determine the resulting grade of the slab surface. In some cases, extremely weak subgrade may need to be remediated.

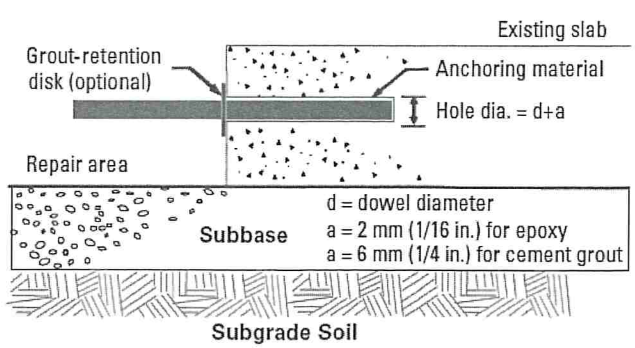
If the base is found to be too high, part of it can be removed. A small milling machine or excavator can be utilized for this purpose, depending on the geometry of the repair and the type of base material.

Load-Transfer Restoration

Cast-in-Place Repairs

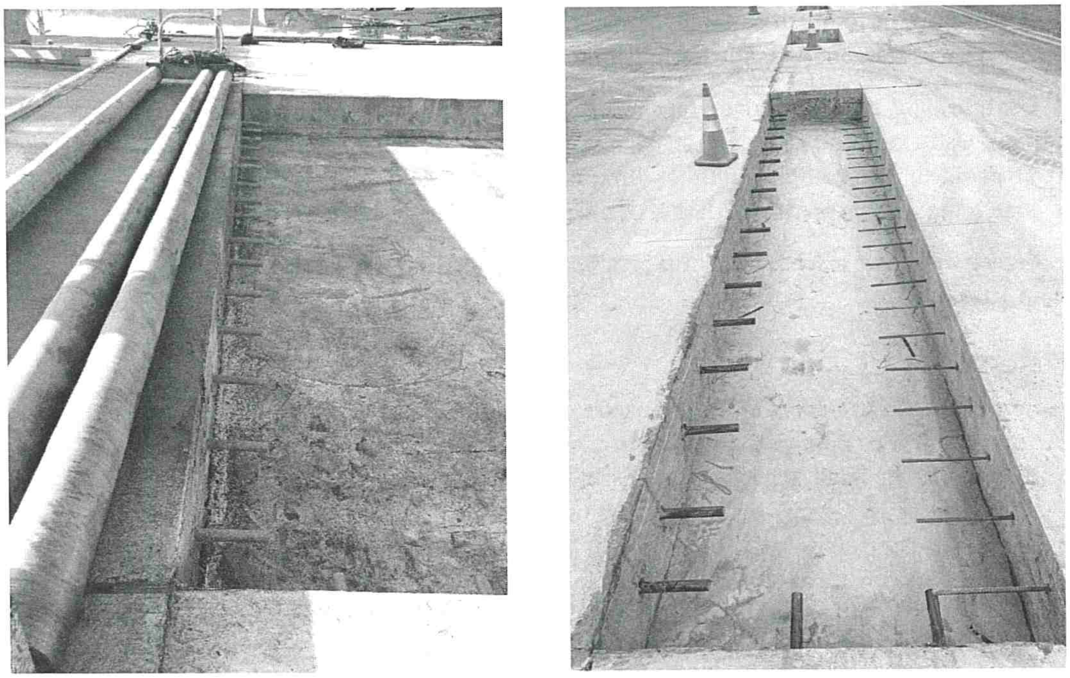
FDR typically requires restoration of load transfer to avoid differential movement that can cause spalling, rocking, pumping, faulting, and breakup of the FDR or adjacent slabs. Following are some key suggestions:

- Use smooth dowel bars along all edges with existing pavement (full-slab replacement).
- An exception to the previous suggestion is given in FAA AC 150/5380-6C (2014b) and in the U.S. DOD *O&M Manual* (2018). These guidelines allow use of tie bars at appropriate locations, such as nonworking joints (e.g., an inner panel joint for a partial-slab replacement) and crack locations. On aprons, dowels are often used at all joints because aircraft loadings may occur in multiple directions.
- Dowels and tie bars are installed into the existing pavement as follows:
  - Verify slab faces are vertical and in sound condition.
  - Drill holes (avoiding existing embedded steel) with gang-mounted pneumatic drills, maintaining proper horizontal and vertical alignment.
  - Clean out drilled holes and ensure proper anchoring of the dowels (Figure 23) or tie bars. Either cement grout or two-component epoxy material can be used to anchor the dowels, and it is important that the material be effectively distributed around the circumference of the dowel.



Source: Smith et al. (2014).

Figure 23. Schematic of properly anchored dowel.



(a) (b)

Source: (a) Nichols Consulting Engineers, Chtd., and (b) C&S Engineers, Inc.

Figure 24. Load-transfer restoration: (a) full-slab replacement using smooth, anchored dowel bars at all joint faces and (b) partial-slab replacement using smooth dowel bars at existing joints and tie bars at the inner panel joint interface.

Figure 24 provides an example of load-transfer restoration using smooth, anchored dowel bars and tie bars.

Precast Slabs

Load-transfer restoration for precast FDR is based on the system being used. Load-transfer design and installation needs to be coordinated with the supplier or producer but will typically involve either cutting slots or drilling and anchoring dowels in the adjacent pavement for the load-transfer system.

Placement and Finishing

Cast-in-Place Repairs

Preparation of conventional concrete for use in FDR is similar to that used for conventional paving operations. However, if VHES or HES concrete is used, the batching and placement time must be significantly shorter and may require the use of automated volumetric mixers that batch and mix the concrete on-site. Proprietary materials should be produced and placed according to the manufacturer's recommendations. For VHES and HES concrete, the producer's and contractor's experience with the material is critical to successful placement.

Placement of FDR materials often uses the edges of the existing pavement as forms, and the concrete is placed, consolidated, and finished by hand. The workability of the mixture needs to be appropriate for manual operations (i.e., more workable than a machine-placed mixture). The contractor should ensure the concrete is well-consolidated around the edges, load-transfer devices, and light cans by using spud vibrators without overvibration or overfinishing (Smith et al. 2014).

It is important to finish concrete to a smooth, textured surface free of unevenness from the paving process. A general guide for finishing includes the following guidance (U.S. DOD 2018):

- Use a straight edge to strike off repairs less than 10 feet (perpendicular to the pavement centerline). Use a vibratory screed to strike off repairs longer than 10 feet (longitudinal direction).
- To avoid surface scaling and other durability problems, do not overfinish the concrete.
- Match the surface texture with that of the adjacent slabs.

Figure 25 shows a schematic of typical finishing techniques for repairs shorter and longer than 10 feet.

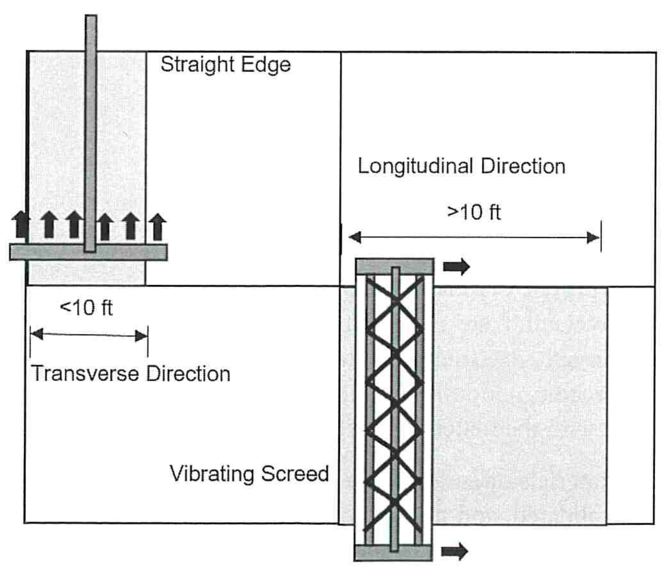
Precast Slabs

Precast slabs for airport applications are often fabricated at an on-site location in advance of construction to ensure that an adequate inventory of slabs exists before work proceeds. Full three-dimensional surveys are often obtained to accurately establish panel dimensions and surface geometry/warping before fabrication begins. Placement and finishing are performed in casting beds, usually with conventional placement techniques. Fabrication of the precast slabs needs to consider reinforcing steel; load-transfer devices; lifting lugs; embedded jacks; grout injection ports; grout distribution channels (if any); slot formers; and in-pavement lighting, if included. The contractor will need to ensure that an adequate number of precast slabs is backlogged before construction begins. Repair area dimensions must be accurately addressed during the fabrication of precast slabs.

Curing

As with PDR, curing is important to FDR to ensure concrete strength gain. Following are key suggestions for proper curing practices (Smith et al. 2014, U.S. DOD 2018):

- The approved curing procedure should be started as soon as the bleed water has dissipated from the surface of the concrete.
- Curing methods to retain water include impervious paper, pigmented curing membrane, wet burlap, or polyethylene sheeting. The use of a white-pigmented curing compound (ASTM C309 Type 2) is most common, with typical application rates between 100 and



Source: Nichols Consulting Engineers, Chtd.

Figure 25. Finishing schematics for patches less than and greater than 10 feet long.

200 square feet per gallon to retain moisture. PAMS curing compounds (ASTM C309 Type 2, Class B) are typically more expensive than wax- and water-based compounds but are more effective at retaining water and should be considered.
- For concrete with an early opening to traffic and concrete placed under low temperatures, insulation blankets can be used to keep the internal temperature of the concrete high. This accelerates the rate of hydration, which results in a rapid strength gain. For conventional concrete, insulation blankets can be used when the ambient temperature is low (<48°F), the winds are high, or both (American Concrete Institute 2016).

Follow the manufacturer's recommendations for proprietary products if curing methods differ from traditional methods.

After curing, joints are prepared and sealed. Joint sealing operations can typically be performed during a subsequent closure following the sealant manufacturer's recommendations if minimum curing requirements exist.

Conventional curing methods are generally used for precast FDR at the place of fabrication. In some cases, external heat is applied to accelerate strength gain.

Pavement Grinding and Grooving

The finished concrete surface should be level with the surface profile of adjacent slabs. However, these repairs may result in increased roughness, and diamond grinding is often performed to restore rideability and create a smooth pavement (Smith et al. 2014). The FAA's P-501 cement concrete pavement specification indicates that variances greater than 0.25 inch in 12 feet should be diamond ground, as this difference may allow water to pond and thereby increase the risk of aircraft hydroplaning (FAA 2018).

For existing grooved surfaces (primarily runways), grooving should be reestablished in accordance with FAA AC 150/5320-12C, *Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces* (FAA 1997). Care should be taken to match adjacent grooves and to not extend new grooving into adjacent slabs. Grooving can typically be performed during a separate closure after completion of the primary FDR work. Proper cleanup after grooving is an important step before reopening to traffic.

Joint Resealing and Marking

Following grooving, joints should be sawed to the proper width and cleaned, and a backer rod should be inserted to the correct depth to create the sealant reservoir. Joint sealant is placed in accordance with specifications and the manufacturer's recommendations.

FDR of large pavement areas can create the need to replace pavement markings and/or provide temporary pavement markings. FAA AC 150/5370-10H (FAA 2018) provides comprehensive guidance on temporary and permanent pavement markings.

Opening to Traffic

Cast-in-Place Repairs

There are two methods for determining when FDRs can be opened to traffic:

- Specified minimum strength (typically 550 psi flexural strength for aircraft loading) or
- Specified minimum time after completion of the repair (varies depending on material type).

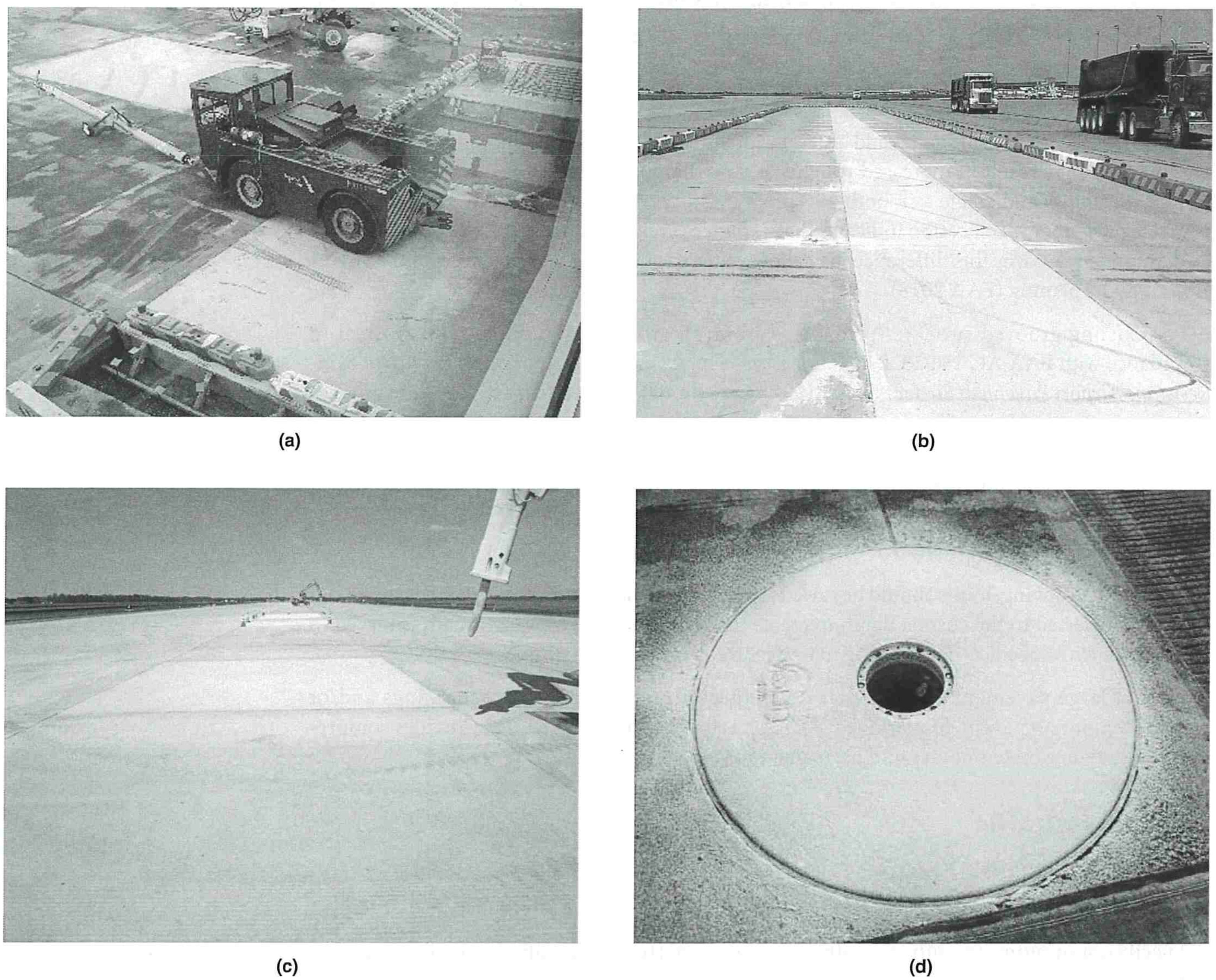
The logistics of measuring strength is difficult, especially for VHES materials. An alternative method of assessing strength gain, such as ASTM C1074, *Standard Practice for Estimating Strength by the Maturity Method*, could be considered.

FAA AC 150/5370-16 (FAA 2007) states that a thorough inspection [by the (airport's) project manager] should be done prior to reopening pavement to aircraft operations. The project manager must ensure all items meet the following requirements:

- Construction materials have been secured.
- Concrete has met the required opening strength.
- All pavement surfaces have been cleaned and construction debris removed.
- All surfaces have been marked for safe aircraft operation.

Good communications must be established by airport operations to maintain good coordination for closures and reopening. Also refer to FAA AC 150/5370-2G, *Operational Safety on Airports During Construction* (FAA 2017).

Figure 26 shows examples of completed cast-in-place FDRs at airfield facilities.



Source: (a–c) Nichols Consulting Engineers, Chtd., and (d) Rummel Construction.

Figure 26. Examples of completed cast-in-place full-depth repairs: (a) full slabs, (b) partial slabs, (c) full slabs, and (d) replacement of in-pavement light.

Precast Slabs

Precast FDRs do not have the concern of concrete curing. While the grout for the load-transfer system needs to achieve the required strength, it is typically a VHES material. Otherwise, the general cleanup items are as noted above.

Full-Depth Repair Assessment Tool

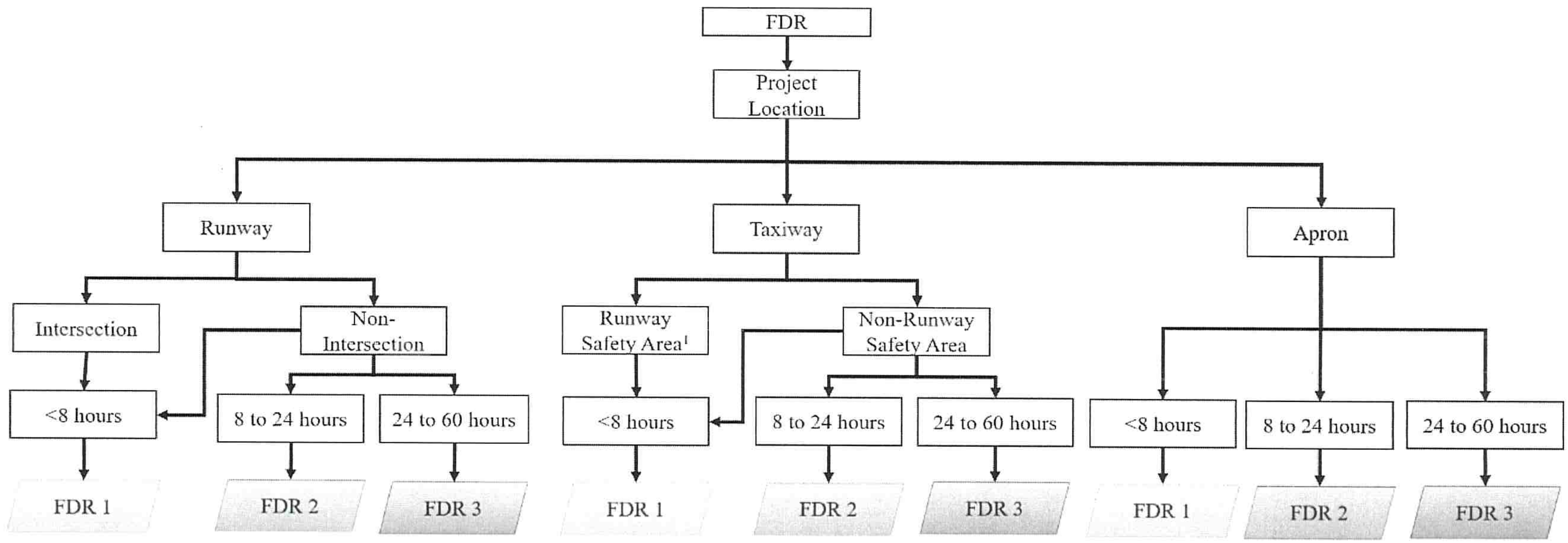
Figure 27 and the associated tables (Tables 17–19) present a framework for assessing some of the key variables considered during planning for and completing FDRs. This tool provides users with practical guidance on feasible techniques for repair of concrete pavement for a variety of facilities and closure times.

Figure 27 presents a decision tree for identifying the location of the planned FDR.

1. Select the facility on which the FDR will be completed (i.e., runway, taxiway, or apron).
2. Identify the relative operational priority of the repair area (e.g., runway intersection, runway safety area).
3. Determine how much time is available to do the work. Closure time is divided into three groups:
   - Less than 8 hours (equivalent to an overnight closure),
   - 8 to 24 hours (equivalent to a 1-day closure), and
   - 24 to 60 hours (equivalent to a weekend closure).

In many instances, work can be scaled to fit into the available closure time. That is, if a closure of less than 8 hours is the only available option for a given material and preparation method, the number of repairs may be limited in a given closure window to ensure all repair areas have achieved the required strength at the time of opening. Similarly, with longer closure time, a more conventional repair material can be used. Longer closure times also permit a higher production rate, as more time is available to work under a single mobilization.

Each set of decisions leads to a table that summarizes the planning and construction considerations associated with the resulting box in Figure 27 (see Table 17 for FDR 1, Table 18 for FDR 2, and Table 19 for FDR 3).



Note: See Table 17, Table 18, and Table 19 for FDR 1, FDR 2, and FDR 3, respectively.
[1]Some taxiway connectors could remain closed to allow for longer curing times as long as work is completed within the allowable closure window.
Source: Nichols Consulting Engineers, Chtd.

Figure 27. Full-depth repair decision framework.

Table 17. Summary of FDR 1 decisions.

FDR 1 (<8 hours)	
Preparation	
Repair types and location	• Partial slab: Encompass all deteriorated concrete and underlying layers (deterioration at the bottom of the slab can extend as much as 3 feet from visible surface distress). • Full slab: Extend repair to slab edges or include adjacent slabs if sound concrete is not present. • Consider closure time and placement rate in selecting quantity of repairs and ensure the final repair placed during the closure will be able to achieve the required strength at the time of opening.
Material selection	• Allowable closure time can dictate whether VHES materials are needed. Use the most conventional material that meets opening-to-traffic requirements. • Consider climatic conditions and temperature during placement and curing. • Precast slabs are a candidate. • Planning and coordination with precast supplier (panel sizes, locations, characteristics) is required. • Preproject fabrication and stockpiling of panels are required.
Repair boundaries	• Partial-slab repairs allowed. • Minimum width of 3 feet from joint. • Minimum length of 10 feet. • If repair extends over half the length of the panel, full-slab replacement is advised.
Demolition/Removal	
Removal method	• Before removal, saw cut boundaries. • Saw cut in advance to allow earlier closure (but no more than 1 or 2 days in advance). • Avoid saw cut overruns. • Consider shims to minimize slab rocking between closures, if needed. • Adjust saw cut pattern for existing cracks. • An additional saw cut at a specified offset (e.g., 4 inches) into the slab is done to avoid damaging adjacent slabs during removal. • Angle interior saw cuts to ease removal of center piece. • Lift-out method usually minimizes risk of damage to adjacent pavement.
Sublayer repair	• Compact with a plate compactor. • If excess moisture is present, remove or dry it before grading and compaction. • Option to replace some or all disturbed material with rapid strength flowable fill or lean concrete (with bond breaker). • Use geogrid if poor-quality layers are encountered. • Have means to trim stabilized materials, if needed.
Load-transfer restoration and reinforcement	• Dowel bar or tie bar size and spacing vary. • Dowel bars or tie bars along joints and edges tying into the existing pavement (except when an isolation joint is warranted). • Maintain proper horizontal and vertical alignment of dowels. • Ensure proper anchoring of dowels. • Provide reinforcement for odd-shaped slabs.
Material Mixing and Placement	
Mixing and placement	• May require the use of automated volumetric mixers that batch and mix concrete on-site. • If conventional concrete mixes are being used, follow standard mixing and placement practice, including consolidation with internal spud vibration. • Make sure the concrete is well-consolidated around the edges without over-finishing. • Follow the manufacturer's recommendations for proprietary materials.

(continued on next page)

Table 17. (Continued).

FDR 1 (<8 hours)	
Finishing	• Use a vibratory screed if replacement slab is more than 10 feet long. • Use a straight edge if replacement slab is less than 10 feet long. • Do not over-finish concrete. • Match texture with adjacent slabs.
Curing	• Start curing as soon as the bleed water has dissipated from the surface of the concrete. • Use the approved curing method, such as a white-pigmented curing compound. • When warranted, use insulation blankets to maintain strength gain and protect concrete during cold weather.
Joint sealing	• Saw the transverse and longitudinal joint sealant reservoirs of the repair area (do not form reservoirs with insert). • Seal transverse and longitudinal joints around the perimeter of the patched area. Note: Joint sealing performed during separate closure.
Opening to Traffic	
Compressive strength	• 3,500 psi for aircraft loading.
Flexural strength	• 550 psi for aircraft loading.
Other	• Maturity testing as alternative for opening criteria. • Consider whether direct traffic loadings will be likely (i.e., only require strength for an emergency loading as opposed to continuous traffic).

Table 18. Summary of FDR 2 decisions.

FDR 2 (8–24 hours)	
Preparation	
Repair types and location	• Partial slab: Encompass all deteriorated concrete and underlying layers (deterioration at the bottom of the slab can extend as much as 3 feet from visible surface distress). • Full slab: extend repair to slab edges or include adjacent slabs if sound concrete is not present. • Consider closure time and placement rate in selecting quantity of repairs and ensure that final repair placed during the closure will be able to achieve the required strength at the time of opening.
Material selection	• Allowable closure time, high-early or moderate-early materials may be needed. Use the most conventional material that meets opening-to-traffic requirements; accelerated conventional concrete is most widely used material. • Consider climatic conditions and temperature during placement and curing.
Repair boundaries	• Partial-slab repairs allowed. • Minimum width of 3 feet from joint. • Minimum length of 10 feet. • If repair extends over half length of the panel, full-slab replacement is advised.

Table 18. (Continued).

FDR 2 (8–24 hours)	
Demolition/Removal	
Removal method	• Before removal, saw cut boundaries. • Saw cut in advance to allow earlier closure (but no more than 1 or 2 days in advance). • Avoid saw cut overruns. • Consider shims to minimize slab rocking between closures, if needed. • Adjust saw cut pattern for existing cracks. • Consider an additional saw cut at a specified offset (e.g., 4 inches) into the slab to avoid damaging adjacent slabs during removal. • Angle interior saw cuts to ease center piece removal. • Lift-out method usually minimizes risk of damage to adjacent pavement.
Sublayer repair	• Compact with a plate compactor. • If excess moisture is present, remove or dry it before grading and compaction. • Option to replace some or all disturbed material with rapid strength flowable fill or lean concrete (with bond breaker). • Use geogrid if poor-quality layers are encountered. • Have means to trim stabilized materials, if needed.
Load-transfer restoration and reinforcement	• Dowel bar or tie bar size and spacing varies. • Dowel bars or tie bars along joints and edges tying into the existing pavement (except when an isolation joint is warranted). • Maintain proper horizontal and vertical alignment of dowels. • Ensure proper anchoring of dowels. • Provide reinforcement for odd-shaped slabs.
Material Mixing and Placement	
Mix and placement	• Follow standard mixing and placement practice for conventional concrete mixes, including consolidation with internal spud vibration. • Make sure the concrete is well-consolidated around the edges without over-finishing. • Follow the manufacturer's recommendations for proprietary materials.
Finishing	• Use a vibratory screed if replacement slab is more than 10 feet long. • Use a straight edge if replacement slab is less than 10 feet long. • Do not over-finish concrete. • Match texture with adjacent slabs.
Curing	• Start curing as soon as the bleed water has dissipated from the surface of the concrete. • Use the approved curing method, such as a white-pigmented curing compound. • When warranted, use insulation blankets to maintain strength gain and protect concrete during cold weather.
Joint sealing	• Saw the transverse and longitudinal joint sealant reservoirs of the repair area (do not form reservoirs with insert). • Seal transverse and longitudinal joints around the perimeter of the patched area. Note: Joint sealing performed during separate closure.
Opening to Traffic	
Compressive strength	• 3,500 psi for aircraft loading.
Flexural strength	• 550 psi for aircraft loading.
Other	• Maturity testing as alternative for opening criteria. • Consider whether direct traffic loadings will be likely (i.e., only require strength for an emergency loading opposed to continuous traffic).

Table 19. Summary of FDR 3 decisions.

FDR 3 (24–60 hours)	
Preparation	
Repair types and location	• Partial slab: encompass all deteriorated concrete and underlying layers (deterioration at the bottom of the slab can extend as much as 3 feet from visible surface distress). • Full slab: extend repair to slab edges or include adjacent slabs if sound concrete is not present. • Consider closure time and placement rate in selecting quantity of repairs and ensure that final repair placed during the closure will be able to achieve the required strength at the time of opening.
Material selection	• For allowable closure time, slightly accelerated conventional concrete mix will likely meet the opening requirements. • Consider climatic conditions and temperature during placement and curing.
Repair boundaries	• Partial-slab repairs allowed. • Minimum width of 3 feet from joint. • Minimum length of 10 feet. • If repair extends over half length of the panel, full-slab replacement is advised.
Demolition/Removal	
Removal method	• Before removal, saw cut boundaries. • Saw cut in advance to allow earlier closure (but no more than 1 or 2 days in advance). • Avoid saw cut overruns. • Consider shims to minimize slab rocking between closures, if needed. • Adjust saw cut pattern for existing cracks. • Consider an additional saw cut at a specified offset (e.g., 4 inches) into the slab to avoid damaging adjacent slabs during removal. • Angle interior saw cuts to ease removal of center piece. • Lift-out method usually minimizes risk of damage to adjacent pavement.
Sublayer repair	• Compact with a plate compactor. • If excess moisture is present, remove or dry it before grading and compaction. • Option to replace some or all disturbed material with rapid strength flowable fill or lean concrete (with bond breaker). • Use geogrid if poor-quality layers are encountered. • Have means to trim stabilized materials, if needed.
Load-transfer restoration and reinforcement	• Dowel bar or tie bar size and spacing vary. • Dowel bars or tie bars along joints and edges tying into the existing pavement (except when an isolation joint is warranted). • Maintain proper horizontal and vertical alignment of dowels. • Ensure proper anchoring of dowels. • Provide reinforcement for odd-shaped slabs.
Material Mixing and Placement	
Mix and placement	• If conventional concrete mixes are being used, follow standard mixing and placement practice, including consolidation. • Make sure the concrete is well consolidated around the edges without over-finishing. • Follow the manufacturer's recommendations for proprietary materials.
Finishing	• Use a vibratory screed if replacement slab is more than 10 feet long. • Use a straight edge if replacement slab is less than 10 feet long. • Do not over-finish concrete. • Match texture with adjacent slabs.

Table 19. (Continued).

FDR 3 (24–60 hours)	
Curing	• Start curing as soon as the bleed water has dissipated from the surface of the concrete. • Use the approved curing method, such as a white-pigmented curing compound. • When warranted, use insulation blankets to maintain strength gain and protect concrete during cold weather.
Joint sealing	• Saw the transverse and longitudinal joint sealant reservoirs of the repair area (do not form reservoirs with insert). • Seal transverse and longitudinal joints around the perimeter of the patched area. Note: Joint sealing performed during separate closure.
Opening to Traffic	
Compressive strength	• 3,500 psi for aircraft loading.
Flexural strength	• 550 psi for aircraft loading.
Other	• Maturity monitoring as alternative for opening criteria.

CHAPTER 5

Conclusions

Proper maintenance and repair of concrete airfield pavements are critical to their longevity and ability to safely support airport operations over their design life. However, these activities can be costly and operationally disruptive, as they require closure of the pavement facility. To minimize the construction impacts, airports of all sizes are relying on RSRR activities that include PDR and FDR. FAA AC 150/5370-16, *Rapid Construction of Rigid (Portland Cement Concrete) Airfield Pavements* (FAA 2007), addresses many key components and considerations for accelerated concrete construction, but stops short of providing sufficient details or specific methods to aid airport personnel or consulting engineers in making informed decisions. Furthermore, AC 150/5370-16 focuses on larger areas of concrete replacement and provides only limited information on individual slab replacement or smaller repairs. In addition, FAA Item P-501, "Portland Cement Concrete Pavement" in AC 150/5370-10H, *Standard Specifications for Construction of Airports* (FAA 2018), does not provide specifications for construction featuring ESC or prepackaged repair materials used in RSRR projects.

This guidebook was developed to assist airport personnel and engineering consultants in selecting and executing RSRR projects. A successful RSRR project requires attention to all phases of the project, beginning with planning and ending with reopening the pavement to aircraft after the construction is completed.

Stakeholder coordination, airfield facility closures, high construction costs, and lack of experience with ESC repair materials are major challenges in RSRR. While the level of stakeholder coordination and challenges with airfield facility closures vary across airports (by size and function), high costs and lack of experience with these types of evolving materials are a universal challenge. In general, large hub airports have good experience with RSRR, and some have advanced, well-developed programs in place. Importantly, elements of their RSRR programs and practices can easily be applied by smaller airports (e.g., nonhub primary and general aviation), which are less likely to have RSRR experience.

The following lessons were learned from this study:

- The airports surveyed possess a wide range of experience, from planning to construction. Respondents who reported no previous RSRR experience represented either nonhub primary or general aviation airports.
- Stakeholder coordination and lack of skilled contractors and workforce are primary challenges. While the level of stakeholder coordination varies across airports (by size and function), the lack of skilled contractors and workforce is a universal challenge.
- Airports can minimize the need for emergency repairs by maintaining a good internal pavement inspection program and utilizing the results of their pavement management system to track deterioration and identify repair needs.

- Stakeholder coordination throughout the process is essential. This includes all affected parties, such as airport operations, airlines and cargo carriers, contractors, producers, and testing firms. Communication should start from the earliest stages of planning and continue daily through construction. Contingency planning to address unexpected circumstances is important.
- The supplier should be included in the planning and construction processes. This is especially critical if proprietary materials are being used. Material suppliers should provide training to ensure crews are knowledgeable about specific requirements for material handling and installation. Manufacturer's recommendations should always be followed when working with prepackaged PDR materials.
- Many airports reported that a design–bid–build process is the most effective way to deliver RSRR projects.
- Using an existing design team or on-site contractor or both can accelerate the overall RSRR process.
- Nearly all PDRs and FDRs are placed under nonemergency conditions and are typically performed by contractors. When emergency PDRs are required, it is common to perform temporary repairs in critical aircraft traffic areas (e.g., runways, taxiways). These repairs are performed during short closures and replaced with permanent repairs when aircraft operations permit longer closure times.
- Permanent PDRs and FDRs should be constructed at the opportune time. Factors used to determine construction timing include periods with lower aircraft traffic and more favorable weather conditions for construction (i.e., not during hot summer months or seasonal times of high precipitation). Coordination with stakeholders is required to minimize disruption to airline operations.
- If possible, the construction time required for proper PDR and FDR installation should govern the closure time. Although this is not always possible, airports should try to establish the longest possible closure windows to provide the greatest amount of time to execute quality repairs.
- Regardless of experience, contractors should be required to construct repair mock-ups off-site prior to starting work on the airfield. Contractors should initiate on-site work on the least critical areas of the airfield (i.e., apron and taxiway, then runway slabs) to gain experience (or refamiliarize their crews) with accelerated airfield construction.
- In some cases, protecting existing concrete from damage during demolition is a challenge. This should be carefully considered and methods developed to minimize damage prior to full-scale construction.
- Attention to detail during construction is essential to obtaining quality repairs. This includes monitoring the weather to ensure construction does not occur during adverse conditions.
- Prepackaged VHES or HES cementitious materials are the most frequently used materials for PDR. Opening to traffic for PDRs is commonly based on time after placement, in accordance with manufacturer recommendations.
- VHES or HES mixtures are often used for FDR. The opening times for FDRs are commonly determined through flexural or compressive strength testing.
- For larger FDR projects, dedicated concrete batch plants should be located on-site or close by with a dedicated gate provided for airfield access.
- The initial volume of concrete produced by some mobile equipment (e.g., volumetric mixer) can have poor moisture control, which has a negative impact on workability. If possible, modern mobile mixers with electronic control should be specified to address this problem.
- Providing the contractor with a secured area facilitates timely completion of the work.
- Maintaining safety and security during construction requires a significant commitment of airport personnel.

- Some airports rely heavily on local airport and contractor experience with repair materials and methods, this knowledge having been developed over many years.
- Building on past experiences helps airports eliminate some of the risk associated with RSRR projects. This includes both material selection and methods. New materials and methods should be introduced cautiously, with localized experimentation before full-scale adoption.
- Airport satisfaction with RSRR performance is mixed, with shorter-than-expected service life cited as the main reason for dissatisfaction.

When airports are carrying out initial RSRR projects, it is important that they set realistic expectations and plan for issues to arise during the initial phases of construction. This guidebook, the case examples in Appendix A, and the project examples in Appendix B can be used as a starting point to develop RSRR strategies that meet the needs of individual airports.

This guidebook can be used in its entirety by airports that do not regularly carry out RSRR projects, or specific sections can be used as needed. Either way, this volume provides a comprehensive tool for carrying out RSRR projects.

Abbreviations

AC	Advisory Circular
ACPA	American Concrete Pavement Association
ARFF	aircraft rescue and fire fighting
ASTM	American Society for Testing and Materials
ATL	Hartsfield–Jackson Atlanta International Airport
CMH	John Glenn Columbus International Airport
CSA	calcium sulfoaluminate
CSPP	construction safety and phasing plan
CTE	coefficient of thermal expansion
CVG	Cincinnati/Northern Kentucky International Airport
cwt	hundredweight
DOT	Department of Transportation
ERDC	U.S. Army Engineer Research and Development Center
ESC	early-strength concrete
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FDR	full-depth repair
FOD	foreign object debris
GPR	ground-penetrating radar
GRR	Gerald R. Ford International Airport
HES	high-early-strength
LAS	McCarran International Airport
LAX	Los Angeles International Airport
LTPP	Long-Term Pavement Performance
MES	moderate-early-strength
NCE	Nichols Consulting Engineers, Chtd.
NOTAM	notice to airmen
O&M	operations and maintenance
PAMS	poly(alpha-methylstyrene)
PCI	pavement condition index
PDR	partial-depth repair
PHX	Phoenix Sky Harbor International Airport
PPE	personal protection equipment
psi	pounds per square inch
QC/QA	quality control/quality assurance
RDU	Raleigh–Durham International Airport
RSRR	rapid slab repair and replacement

SEA	Seattle–Tacoma International Airport
SDF	Louisville Muhammad Ali International Airport
SFO	San Francisco International Airport
USAF	U.S. Air Force
VHES	very high-early-strength
w/cm	water to cement (ratio)
YVR	Vancouver International Airport

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APPENDIX A

Airport Case Examples

This appendix provides case examples of rapid slab repair and replacement (RSRR) practices and programs at several airports. In addition to completing the online surveys, airport engineer(s) or the airport's consultant, or both, participated in a detailed interview; the information presented here summarizes the information from the surveys and interviews.

Table A-1 lists the airports that are featured in these case examples. The case examples are presented in order from west to east and according to FAA region and associated Long-Term Pavement Performance (LTPP) program climatic region (FHWA 2016).

While these examples represent mainly large hub airports, most information presented can be applied to airports of any size. Each case example provides the following information:

- Overview of the airport and general information about RSRR practice,
- RSRR program highlights,
- Challenges, and
- Key takeaways.

RSRR Practice at Seattle–Tacoma International Airport

Overview

Seattle–Tacoma International Airport (SEA) is a large hub airport located in Seattle, Washington. Nearly all aircraft-bearing pavements are concrete. SEA initiated an RSRR program around 1994, and it has evolved through trial and error, capitalizing on lessons learned from numerous projects. Table A-2 provides an overview of SEA's RSRR practice.

The airport does not monitor PDR performance. FDR performance is monitored as part of SEA's annual pavement inspection program. Before SEA started its RSRR program, a typical service life for an FDR was 10 years. Since then, FDRs have lasted 15 to 20 years. Minimal to no cracking has been reported in recent PDRs. The airport identified quick setting time, which has a negative impact on concrete finishing, and low strength, which can lead to cracking, as key factors that can lead to poor performance.

RSRR Program Highlights

- **Regardless of experience, the contractor is required to construct a mock-up panel off-site prior to starting work on the airfield.** This provides the opportunity for the contractor's crews to familiarize themselves with the behavior of the concrete mixture. SEA found that the behavior of VHES CSA cement concrete changes frequently, even during the same job.

Table A-1. Airports with highlighted RSRR practice.

Airport	FAA Region	LTPP Climate Region
Seattle–Tacoma International	Northwest Mountain	Wet, nonfreeze
Vancouver International	na[a]	Wet, nonfreeze
Los Angeles International	Western Pacific	Dry, nonfreeze
McCarran International	Western Pacific	Dry, nonfreeze
Phoenix Sky Harbor International	Western Pacific	Dry, nonfreeze
John Glenn Columbus International	Great Lakes	Wet, freeze
Hartsfield–Jackson Atlanta International	Southern	Wet, nonfreeze
Louisville Muhammad Ali International	Southern	Wet, nonfreeze
Raleigh–Durham International	Southern	Wet, nonfreeze

Note: na = not applicable.
[a]Similar to Northwest Mountain.

Table A-2. Overview of RSRR practice at Seattle–Tacoma International Airport.

Category	Item	Detail
Airport information	Airport location	Seattle, Washington
	Owner	Port of Seattle
	FAA classification	Large hub
	FAA region	Northwest Mountain
	LTPP climate region	Wet, nonfreeze
	Number of runways	Three parallel
Planning	Stakeholder communications	FAA control tower and airport-operated ramp tower (for apron repairs) Airlines Airport operations and fire department
	Allowable closures	All facilities: 6-hour night closure (11:00 p.m. to 5:00 a.m. typical) Aprons: Some exceptions for day closures with airline approval
	Funding	Airport
	Emergency work	Rarely done, as concrete pavements in aircraft movement areas are kept in good condition
	Project delivery	Design–bid–build
	On-call contractors?	No
Design	Designer	Port of Seattle
	Design documents	FDR: Plans and specifications
	Specification elements	Liquidated damages for exceeding closure windows Requires backup equipment
	In-pavement lights	Single light: Steel reinforcement around the light can Multiple lights: Steel reinforcement throughout slab
Construction	Construction	PDR: Airport maintenance crews FDR: Contractors
	PDR materials	Epoxy concrete (prepackaged)
	FDR materials	Specialty cement (CSA)
	Material testing	Port of Seattle personnel
	Inspection	Port of Seattle personnel
	QC/QA elements	Onsite inspectors Nuclear gauge to monitor sublayer compaction Concrete testing: Air content, flexural strength, and temperature
	Contingency planning	Airport has its own precast slabs that can be temporarily installed Work is postponed if rain or fog is forecast
	Material acceptance	PDR: None FDR: Flexural testing [550 psi at return to service, 650 psi at 28 days (acceptance)]

- **The contractor must start work on the least-critical areas of the airfield (i.e., apron and taxiway, then runway slabs).** This allows the contractor to gain experience (or refamiliarize its crews) with working on the airfield and with accelerated construction, which slightly lowers the risk of an impact on airport operations if work extends past the return-to-service deadline.
- **The airport conducts a very good internal pavement inspection program.** Sections of the airfield are inspected on an annual (rotating) basis. As a result, SEA can plan for slab repair and replacement activities well in advance.
- **A design–bid–build process with a change order option is used to deliver RSRR projects.** Design is done in house, and each project includes a specific number of slabs for replacement. If the contractor is doing good work, SEA can add 25% additional quantities to the contractor's work without needing the approval of the Port of Seattle Board. Additional work depends on slab location (i.e., runway, taxiway, apron) and whether additional planning or stakeholder coordination is needed.
- **SEA collaborates with a university.** Researchers collect data on the CSA cement mixtures and provide feedback to enhance SEA's RSRR program.
- **SEA permits concrete batch plants on-site for larger projects.** Batch plants can produce a more uniform concrete mixture than mobile volumetric mixing trucks. Oftentimes, these batch plants are already on-site to produce FAA P-501 concrete mixture for conventional construction on the airfield.

Challenges

- Lack of technical knowledge,
- Lack of skilled contractors and workforce, and
- Very high cost of RSRR with VHES concrete (approximately four times greater than P-501 concrete).

Key Takeaways

- Conduct upfront and contingency planning (stated as one of the most important elements for RSRR project success).
- Set realistic expectations when carrying out initial RSRR projects and plan for issues during construction.
- Use VHES concrete only when necessary (i.e., very short closure windows).
- Quick set time of VHES concrete can negatively affect concrete finishing, and low strength can lead to cracking; both are key factors that can lead to poor performance.
- Select an experienced contractor (also important to RSRR project success).
- Establish a backup plan (mainly for repairs in aircraft parking areas) in the event construction extends beyond the closure time frame.
- Monitor the weather forecast and delay FDR if conditions (e.g., rain, fog, high wind) may potentially affect the construction schedule and quality.
- Provide on-site inspectors and material testing. Material testing technicians must be trained or have experience preparing beam specimens with VHES concrete.

RSRR (Cast-in-Place) Practice at Vancouver International Airport

Overview

Vancouver International Airport (YVR) is a large hub airport located in Vancouver, British Columbia, Canada. YVR is Canada's second busiest airport and has two main (parallel) runways. Runway 8L-26R (north runway) is 9,940 feet and was originally built 1996, and Runway 8R-26L

(south runway) is 11,500 feet and originally constructed in 1953 (it currently has a partial asphalt concrete overlay). A third, crosswind runway, is 7,300 feet long.

YVR initiated an RSRR project in 2010 to replace deteriorated slabs on the north runway. Eleven slabs, approximately 20 feet by 25 feet and 15 inches thick, were identified for replacement. Existing slabs contained in-pavement lighting that had to be maintained in the replacement slabs. The replacement slabs were reinforced to control potential cracking. Table A-3 provides an overview of this RSRR project. While formal condition monitoring has not been conducted, the replaced slabs have been performing satisfactorily for 10 years.

RSRR Cast-in-Place Program Highlights

Following are key features of YVR's RSRR cast-in-place program:

- **The contractor was required to construct multiple mock-up panels off-site prior to starting a construction project on the airfield.** This provided the opportunity for the contractor's crews to familiarize themselves with the concrete mixture. For this project, the material was very stiff and required a lot of work for proper placement. The material supplier was part of the team to ensure proper placement.

Table A-3. Overview of a RSRR project at Vancouver International Airport.

Category	Item	Detail
Airport information	Airport location	Richmond, British Columbia, Canada
	Owner	Vancouver Airport Authority
	FAA classification	Large hub
	FAA region	na (similar to Northwest Mountain)
	LTPP climate region	Wet, nonfreeze
	Number of runways	Two parallel and one crosswind
Planning	Stakeholder communications	Air control tower Airlines Airport operations
	Allowable closures	59 hours
	Funding	Airport
	Project delivery	Design–bid–build
Design	Designer	Consultant
	Design documents	Plans and specifications
	Specification elements	Liquidated damages for exceeding closure windows Requires backup equipment, backup batch plant, weather contingency plans, and so forth
	In-pavement lights	Yes
Construction	Construction	Contractor
	PDR materials	Consultant
	FDR materials	Proprietary, HES cement
	Contractor QC	Testing firm
	Construction inspection	Consultant and airport personnel
	QC/QA elements	Onsite inspectors Concrete testing: Air content, slump, and flexural strength
	Contingency planning	Redundant equipment; weather canopies
	Material acceptance	Flexural testing (500 psi at 24 hours, 700 psi at 46 hours)

- **Construction was planned during a time of year and over weekends with lower operations.** Coordination with stakeholders is required to minimize disruption to airline operations.
- **A design–bid–build process was used.** Traditional design in this case allowed time for thorough planning prior to bid and construction. Security access, haul route planning, tower coordination, and what-ifs (i.e., poor weather, material supply issues) were all planned out.
- **The supplier was included in the planning and construction processes.** This helped ensure that a suitable material that met the allowable time restrictions for the FDRs was used.

Challenges

From the perspective of the engineer on this project, the biggest challenges were as follows:

- Short allowable closure times because operations were severely restricted when one runway was closed,
- Lack of a skilled workforce with experience in using accelerated setting materials, and
- The high cost of RSRR with VHES concrete (approximately $50,000 per panel).

Key Takeaways

- Conduct upfront and contingency planning (stated as one of the most important elements for RSRR project success). Acquire security access and identify haul routes in advance due to the nature of material.
- Require the selected contractor to conduct trials with the planned materials. At YVR, this has ensured complete understanding of methods and materials. Airport work only moved forward once all parties were comfortable with the process.
- Require the contractor to prepare a contingency plan for inclement weather conditions. Once work started, it had to be completed (contractor had large canopies to cover work areas in case of rain).
- Provide on-site inspectors and material testing. Material testing technicians must be trained or have experience preparing beam specimens with VHES concrete. Early trials helped all involved parties become more familiar with the material and construction methods.

RSRR (Precast) Practice at Vancouver International Airport

Overview

YVR is a large hub airport located in Vancouver, British Columbia, Canada. It is Canada's second busiest airport and has two main (parallel) runways: Runway 8L-26R (north runway) is 9,940 feet and was originally built 1996, and Runway 8R-26L (south runway) is 11,500 feet and originally constructed in 1953 (it currently has a partial asphalt concrete overlay). A third, cross-wind runway, is 7,300 feet long.

As part of the planning process for an FDR project on the north runway, several design alternatives were assessed. Precast panel replacements were selected as the best alternative on the basis of the allowable 8-hour nightly closure window and life-cycle costs. The controlling factor in the decision was stakeholder needs to minimize runway shutdowns. This factor alone justified the additional cost of precast slabs as compared with the cast-in-place alternatives.

However, the precast panel technology did not appear to have extensive history for typical large panel sizes (and weight) for airside pavements. Therefore, YVR conducted a pilot construction project in 2019 to confirm that the precast slabs would work as anticipated. Table A-4 provides an overview of YVR's precast panel replacement pilot study.

Table A-4. Overview of precast panel pilot study at Vancouver International Airport.

Category	Item	Detail
Airport information	Airport location	Richmond, British Columbia
	Owner	Vancouver Airport Authority
	FAA classification	Large hub
	FAA region	na (similar to Northwest Mountain)
	LTPP climate region	Wet, nonfreeze
	Number of runways	Two parallel, one crosswind
Planning	Stakeholder communications	Air control tower Airlines Airport operations and security
	Allowable closures	8-hour night closure
	Funding	Airport
	Project delivery	Construction manager
Design	Designer	Consultant/contractor/fabricator
	Design documents	Plans and specifications
	Specification elements	Liquidated damages for exceeding closure windows Requires backup equipment, weather contingency plan, and so forth
	In-pavement lights	Yes, in some panels
Construction	Construction	Established methods
	FDR materials	Portland cement–based mixture
	Contractor QC	Testing firm
	Construction inspection	Consultant
	QC/QA elements	Concrete testing: Air content, slump, flexural strength
	Contingency planning	Redundant equipment, weather plan
	Material acceptance	Flexural testing

For the pilot project, a preliminary design document and engineering drawings were developed to illustrate the engineering concepts. These were distributed as an expression of interest, and then a request for proposal was distributed to local contractors. While the precast panel system was not specified, all the submitting teams selected a proprietary panel design. The contractor selected for the project had experience using precast slabs during off-peak hours on a highway project.

Taxiway V was selected for the pilot project, and 12 precast slabs were installed for the study. Conventional cast-in-place techniques were used to repair adjacent pavement. The first eight precast slabs were installed over a period of 4 weeks to refine the installation procedure. Replacement of the last four precast slabs was required to be completed during 8-hour closures to simulate work on the runway, although there was no impending need to reopen the taxiway at the end of the closure.

The contractor was able to set up a precast facility next to the airport and mastered the logistics of fabricating the panels and moving them to the site for installation. Panels were 19.7 feet by 24.6 feet and 14.2 inches thick. The panels were designed as heavily reinforced ductile slabs because conventional design thicknesses would have been much thicker. With fabrication

adjacent to the airport, there were no challenges with transporting the panels from the adjacent site to the taxiway site. If fabricated off-site, the panels would have been difficult to transport on local roads, over bridges, and so forth. The contractor used a conventional large-aggregate mix with low shrinkage. The large aggregate was a concern in areas with a lot of reinforcement or corners. In the future, the contractor would try to have a smaller top-size mix approved for such instances.

The pilot project established a variety of conditions for which unique precast slabs would need to be fabricated; for example, some of the panels included light cans and some did not, and some panels were surrounded by cast-in-place panels and some were adjacent to other precast slabs. These conditions required different reinforcement and load-transfer details.

RSRR Program Highlights

YVR does not have an established RSRR program using precast slabs. This pilot project provided information for additional precast RSRR work at the airport.

Challenges

From the perspective of the consulting engineer, the biggest challenges to carrying out the precast panel pilot project at YVR were as follows:

- There were challenges with the cement-treated base. In some cases, it was high, and part of the base needed to be removed prior to panel installation. The contractor used different techniques to trim the base in high areas, including a small milling machine and excavation equipment, depending on the geometry of the repair. The presence of a lot of base irregularities and associated requirements for base repair would likely eliminate the feasibility of using precast slabs, especially during a short construction window. There were also cases where the cement-treated base was bonded to the existing concrete pavement. The contractor used the lift-out method, and when pieces were bonded, they could break the bond during removal with a dynamic load.
- Five of the precast slab repairs included light cans. Two-piece cans with the upper portion cast in the precast panel were used. One issue with removal and replacement was that the new upper section could not be bolted with the lower section in the cement-treated base. The location of the inset can (in the new slab) was the one that could be controlled, but the lower section could not be connected to the upper section Therefore, tight placement tolerances were required.
- Wind/weather restrictions could come into play for the types of cranes used to lift the panels. This could affect the ability to complete work within an 8-hour shift for a runway. Weather scenarios might require more equipment and different types of equipment during a limited construction window.

Key Takeaways

- Check grades and slab thickness for precast projects.
- Fabricate precast slabs on or near the site to eliminate problems with moving large slabs over public roadways.
- Require previous experience with installation of precast panels; there are many important details that cannot be overlooked. For example, the contractor must be prepared to trim or repair the base material (after panel removal) to accommodate the panel thickness.
- Perform sawing of existing pavement in advance of the 8-hour closure so that the closure begins with lift-out rather than sawing. For the pilot project, sawing around the perimeter

needed to be done on a rail to make sure it was precise enough for the replacement panels and the light can locations. Sawing information was then shown on the shop drawings. To facilitate panel construction, the precision sawing of the perimeter was done several shifts in advance of the actual installation. The internal saw cuts for lift-out were also done in advance.
- Conduct deflection testing on in-place precast slabs after completion of the project work to evaluate load transfer, corner support, and presence of voids or other defects. These results are compared with those obtained from the cast-in-place approach.

Overall, the pilot project illustrated the feasibility of using precast slabs while also illustrating that it is more expensive than conventional, cast-in-place FDR. In this case, the necessity to minimize runway closure times for future repair work made the additional cost acceptable.

RSRR Practice at Los Angeles International Airport

Overview

Los Angeles International Airport (LAX) is a large hub airport located in Los Angeles, California. LAX initiated an RSRR program between 1999 and 2000 that used a VHES mix to repair taxiway pavement between runways. Everything within the runway safety area was constructed with a mixture that achieved a 4-hour flexural strength of 350 psi. LAX does not perform individual slab repairs but has carried out many accelerated construction repairs under tight time constraints. Table A-5 provides an overview of LAX's RSRR practice.

Table A-5. Overview of RSRR practice at Los Angeles International Airport.

Category	Item	Detail
Airport information	Airport location	Los Angeles, California
	Owner	Los Angeles World Airports
	FAA classification	Large hub
	FAA region	Western Pacific
	LTPP climate region	Dry, nonfreeze
	Number of runways	Four parallel
Planning	Stakeholder communications	Air control tower Airlines Airport operations and security
	Allowable closures	Runways have 6- to 7-hour night closures Taxiways and aprons may have longer closures, depending on location Longer (weekend) closures can be planned with stakeholder coordination
	Funding	Federal
	Project delivery	Design–bid–build
Design	Design documents	Plans and specifications
	Specification elements	Liquidated damages for exceeding closure windows Requires backup equipment, weather contingency plan
Construction	Construction	Contractor
	FDR materials	Portland cement–based HES
	QC/QA elements	Concrete testing: Air content, slump, and flexural strength
	Contingency planning	Redundant equipment
	Material acceptance	Flexural testing (350 psi at 4 hours)

In general, LAX's rapid slab repairs have experienced shorter service lives than conventional FDR, primarily due to shrinkage-induced map cracking and surface scaling. Map cracking was related to challenges getting the material to cure properly without cracking. In the airport's experience, the performance of the material being used was highly dependent on temperature. Cooler nighttime temperatures had a large impact on the initial set of the concrete and led to more map cracking. Approximately 40 repaired slabs were subsequently replaced because of the map cracking. Most of the slabs from the project have been removed over the years because of reconstruction of the adjacent runway.

RSRR Program Highlights

- **The contractor is required to construct test sections in noncritical areas (such as aprons) prior to starting construction on a critical area of the airfield.** This provides the opportunity for the contractor's crews to familiarize themselves with the behavior of the concrete mixture. It also allows all the parties involved to become comfortable with the overall accelerated construction process prior to moving into a critical area.
- **A design–bid–build process is used to deliver RSRR projects**. The design process allows working through security access, establishing the haul route, coordinating with the tower, and planning for potential contingencies. Working through the anticipated process and identifying all contingencies during the design stage reduces the likelihood of changes during construction that can cause increases in costs and potentially lead to delays.

A few years ago, LAX employed a City of Los Angeles ordinance allowing the use of a competitive contractor selection process that considers the quality of the team and its experience. This has been included on one project and is being considered for use on future projects. As part of the request for proposal process, LAX requires proposers to submit experience, references, and key personnel (e.g., construction manager, concrete superintendent, quality control manager, safety manager, scheduler, lead engineer). LAX also requires proposed bidders to identify anticipated project challenges and proposed solutions. A hard bid is also required, but the pricing information is sealed and not opened in the initial proposal evaluation. After the responses are ranked, key contractor personnel participate in an interview and are scored on the basis of their responses. The overall scoring includes 50 points for experience and personnel and 50 points based on costs. The cost scoring includes the low bidder receiving 50 points, while the remaining proposers receive scores lower than 50 points. Liquidated damages are enforced for the removal of any key personnel after contract award.

Challenges

From the perspective of the airport engineer, the biggest challenges included

- Access to the site and working among heavy aircraft operations,
- Contractor experience with expedited methods and materials, and
- Closure coordination with stakeholders.

Key Takeaways

- Engage stakeholders early. As part of the work coordination, send notices in a timely manner and submit Form FAA 7460-1 for federally funded projects. It is also essential to involve the FAA Airports District Office early on, as part of the planning process.
- Develop a preliminary phasing plan and work through it with internal operations and the air traffic control tower. Conduct regular meetings with the FAA control tower and terminal radar approach control facilities as well as airline representatives. Plan for monthly meetings, which may become more frequent as the work nears or is underway.

- Plan site access and potential complications when work is being conducted amid active operations. One of the biggest challenges at LAX is getting material to the site, and while the airport does have dedicated construction gates, there is also a vehicle inspection process that must be administered, which requires an additional 5 to 10 minutes. Planning must also consider and coordinate access locations through the airfield and work with airport operations and the air traffic control tower to make sure the materials can get to the job site within specified time limits. These challenges can lead to increased costs (e.g., planning, coordination, extra security, and flaggers). As part of the process, alternative access routes should be considered. For example, a longer service road drive may be faster than waiting to cross busy taxiways.
- Construct a test strip prior to work in critical areas. LAX typically uses parking ramps as test strips. Test strips are not constructed in critical areas, so they provide an opportunity for the contractor to gain familiarity with the materials and the process before it enters the critical areas. Once in critical areas, the construction team has a rough timeline and milestones that must be hit by certain times within the duration of the closure.
- Consider overall project constructability during the planning and design phase. The project may call for a change in design to create subsurface layers that can be placed more rapidly. For example, substituting granular or asphalt materials for econocrete may make the project more constructible in a short closure window.

RSRR Practice at McCarran International Airport

Overview

McCarran International Airport (LAS) is a large hub airport located in Las Vegas, Nevada. While LAS does not have a formalized RSRR program, it has more than 20 years of experience with RSRR and has developed a very detailed approach to planning, engineering, and construction oversight that yields well-performing PDR and FDR. PDR is performed more regularly than FDR. The traffic levels and airport configuration allow construction timing to dictate the closure time rather than the opposite. This unique combination allows most PDRs and FDRs to be constructed with conventional materials in lieu of early-strength materials. Table A-6 provides an overview of LAS's RSRR practice.

Overall, LAS is satisfied with the performance of its PDRs and FDRs. PDRs last several years, with performance dependent on location relative to traffic. If not properly constructed, PDRs are easily damaged or dislodged during runway rubber removal operations. Factors that negatively affect performance include placing PDRs in hot weather, poor surface preparation, use of concrete mixtures that do not meet the coarseness and workability factors described in FAA's P-501 specification, and lack of construction oversight.

RSRR Program Highlights

- **The airport conducts weekly inspections to identify locations requiring PDR and FDR.** Work is scheduled for the following week. Any future larger-scale work is discussed with FAA on a weekly basis. This approach minimizes surprises and allows work and closures to be planned and scheduled well in advance, which results in better-quality PDRs and FDRs.
- **Construction time required for proper PDR and FDR installation almost always governs the closure time.** This approach results in longer service life and works for LAS because it has several aircraft traffic configurations that permit longer closures on runways and taxiways.
- **Temporary PDRs are done to address emergency repair needs in critical aircraft traffic areas (e.g., runways, taxiways).** These repairs are performed during short closures and replaced with permanent repairs when aircraft traffic configuration permits longer closure times

Table A-6. Overview of RSRR practice at McCarran International Airport.

Category	Item	Detail
Airport information	Airport Location	Las Vegas, Nevada
	Owner	Clark County
	FAA classification	Large hub
	FAA region	Western Pacific
	LTPP climate region	Dry, nonfreeze
	Number of runways	Two sets parallel, open V configuration
Planning	Stakeholder communication	Air control tower Airport operations Traffic management unit Airlines and tenants
	Allowable closures	PDR and FDR: Construction time governs closure time
	Funding	Airport
	Project delivery	Design–bid–build Change order to existing contract Solicit quotes from local contractors
Design	Design documents	Plans and specifications Typical details from past projects
	Specification elements	Project-specific QC/QA requirements Liquidated damages
Construction	Construction	PDR: Airport maintenance crews or contractors FDR: Contractors with concrete experience on the airfield
	PDR materials	Prepackaged: Cementitious and noncementitious
	FDR materials	Portland-cement based, HES
	QC/QA elements	Concrete testing: Unit weight and compressive strength
	Contingency planning	Preconstruction meeting Backup construction dates included in planning

necessary for proper construction. Weekly meetings provide opportunity for stakeholder input on upcoming closures.

- **Permanent PDRs and FDRs are constructed at the opportune time.** Factors that are used to determine construction timing include periods with lower aircraft traffic and favorable weather conditions for construction (i.e., not during hot summer months when longer takeoff distances are required).
- **For nonemergency work, detailed presentations are provided to stakeholders (e.g., control tower, airlines, tenants) during the planning stage.** This includes information on the planned closures, work areas, haul routes, site visits, and so forth. Stakeholders have an opportunity to provide input regarding impacts on their operations.
- **Closures for permanent PDRs and FDRs are planned well in advance.** This allows proper time to coordinate work with stakeholders and the use of more conventional construction techniques and materials.
- **LAS has an established procedure when design plans are not prepared.** This procedure includes
  - Use of applicable design details from previous projects;
  - A preconstruction safety briefing with the engineer, contractor, and airport operations;
  - Exhibits showing project site and barricade locations; and
  - Full escort from the airport operations group during construction.
- **The cause of failure is investigated prior to determining permanent treatment.** This information helps LAS improve its RSRR practice and may result in an FDR rather than PDR to avoid returning for subsequent repairs.

- **Suppliers of PDR material are required to provide regular training to airport maintenance personnel.** This ensures crews are knowledgeable about specific material handling and installation requirements.
- **Concrete mixtures used for FDRs are required to meet P-501 specifications for coarseness and workability factors.** This has led to a significant reduction in spalling distress.
- **Construction oversight and attention to details result in better-quality PDRs and FDRs.** Examples include performing work during optimal weather (on the basis of material type), thorough cleaning of the repair area, and monitoring of material conditions (e.g., discarding material that starts to set before installation).

Challenges

From the perspective of the airport, the biggest challenges to carrying out successful RSRR projects at LAS include planning closures to avoid peak aircraft traffic times and less optimal seasons. Summer temperatures can be very high in Las Vegas, which complicates PDR and runway closures (large aircraft operations need to use the longest runway).

Key Takeaways

- Conduct weekly pavement inspections and meetings with FAA to coordinate RSRR work. Engage with other stakeholders (e.g., airlines, tenants) once the work locations are identified and the initial planning is completed.
- Use detailed meetings, presentations, visual exhibits, and site visits to engage stakeholders and plan RSRR work on the airfield.
- Schedule work during periods with lower aircraft operations and when climatic conditions are more favorable to construction. This permits longer closure times (sometimes more than a week) to properly construct PDRs and FDRs.
- Use caution when considering PDR materials that require blending three or more components. There is increased risk of improper mixing of these materials during construction. Also, these products tend to produce a fixed volume of material per batch, which may be more than is needed for the planned PDRs or may set before the batch is fully used.
- Install PDR material higher than the surrounding concrete and then grind flush once it sets to create a level surface. This approach results in a better-performing PDR.
- Store and install PDR materials per the manufacturer's recommendations. (This is very important!) Only mix the amount needed for the repairs and discard any material that starts to set. Do not install PDRs when pavement surface temperatures are very high or when the temperature differential between the pavement and PDR material is great. Store materials in a cool place; consider using chilled water to reduce pavement surface temperatures.
- At LAS, the minimum size of FDRs in noncritical areas (e.g., apron or outside aircraft main gear paths) is one-half of a slab. Only full-slab replacement is used in critical areas that are expected to experience aircraft loading.
- LAS uses conventional concrete paving mixtures for FDR but includes a relatively high total cementitious content (compressive strength requirement of 6,000 psi at 28 days) and a retarding admixture. Compressive strength tests provide more consistent results than tests of flexural strength, and the FDR can be returned to service once a compressive strength of between 4,000 and 4,500 psi is achieved (typically 2 to 3 days).
- Design and construct PDRs and FDRs for long-term performance. FDRs that have been completed since LAS began adhering to the coarseness and workability factors described in FAA's P-501 specification and using 45-degree beveled joint edges have exhibited much better performance (minimal to no spalling) than those constructed in the past.
- Emphasize attention to detail during construction to improve service life. This includes adequate construction oversight, attention to concrete mixture proportioning, and acceptance testing.

- Provide airport maintenance personnel with annual training from suppliers of PDR repair material, including a site visit and demonstrations on handling and installing materials.
- Select a contractor that has good experience with early-strength materials and working in the airfield environment.

RSRR Practice at Phoenix Sky Harbor International Airport

Overview

Phoenix Sky Harbor International Airport (PHX) is a large hub airport located in Phoenix, Arizona. The airport has concrete pavements for runways, all main taxiways but one, and most aprons. PHX has been performing RSRR for many years but recently began to formalize the process by documenting practice and preparing standard procedures. PHX's maintenance crews can perform PDRs (and some FDRs) and the airport has engineering, laboratory testing, and construction inspection support from the City of Phoenix. Table A-7 provides an overview of PHX's RSRR practice.

The airport does not have a formalized process for monitoring specific PDR and FDR performance. In general, PDRs last between 9 months and 3 years, depending on the repair conditions (i.e., size, depth, condition during placement). The airport does not have concerns related to FDR performance, as these repairs typically perform well until they are replaced during the next large construction project (FAA funded).

RSRR Program Highlights

Following are highlights of some of the key features of PHX's RSRR program:

- **PDR work is performed almost daily at the airport.** Airport maintenance crews use a single product (noncementitious material) for all repairs. This helps the crews understand how to mix, handle, and install the repair material as well as how the material behaves during different climatic conditions.
- **Advance coordination is crucial to the success of RSRR work.** Airport operations plays a key role in coordinating work and is involved during all planning stages.
- **Airport operations handles safety and phasing if design plans are not prepared.** This is done as part of the preconstruction meeting and includes site access requirements, badging, haul route planning, and so forth.
- **The City of Phoenix (airport owner) provides design and construction support.** This includes preparation of design plans and specifications, construction inspection, and material testing. The city designers determine whether repair or replacement of sublayers is necessary during FDR.
- **The City of Phoenix materials group provides technical input to the airport.** This includes recommendations on material selection, specifically, selection of HES concrete mixtures. The group is aware of available (and city-approved) mixtures at local concrete plants.

Challenges

Following are the biggest challenges to carrying out successful RSRR projects:

- Material selection, as a result of constantly evolving concrete mixtures using different constituent materials (e.g., fly ash, admixtures);
- Lack of a process for reviewing and considering new types of proprietary repair materials;
- Lack of technical knowledge within the maintenance group;
- Poor long-term performance of PDR repairs;

Table A-7. Overview of RSRR practice at Phoenix Sky Harbor International Airport.

Category	Item	Detail
Airport information	Airport location	Phoenix, Arizona
	Owner	City of Phoenix
	FAA classification	Large hub
	FAA region	Western Pacific
	LTPP climate region	Dry, nonfreeze
	Number of runways	Three parallel
Planning	Stakeholder communications	Emergency PDR only: Airport operations coordinates closures Nonemergency (nonmovement area): Airport operations coordinates closures Nonemergency (movement area): City of Phoenix project manager or a consultant handles stakeholder coordination (airlines, airport, and so forth)
	Allowable closures	Runways: 8-hour night closure (typically 10:00 p.m. to 6:00 a.m.) Taxiways: Nighttime closure preferred Aprons: Nighttime closure preferred; weekend closure possible
	Funding	Airport: PDR and FDR (two panels or fewer) FAA: FDR (more than two panels)
	Emergency work	PDR only
	Project delivery	Job-order contract for large projects On-call contract for smaller, noncritical PDR and FDR
	On-call contractors?	Yes (job-order contract)
Design	Designer	City of Phoenix
	Design documents	FDR: Plans and specifications
	In-pavement lights	Steel reinforcement around the light can
	Form FAA 7460-1	Only submitted if work affects FAA systems or is FAA funded
Construction	Construction	PDR: Airport maintenance crews FDR: contractors, airport crews starting to do some FDR
	PDR materials	Noncementitious repair material
	FDR materials	Portland cement–based concrete with accelerators, sometimes specialty cement
	Material testing	City of Phoenix personnel
	Construction inspection	City of Phoenix personnel
	QC/QA elements	City of Phoenix standard procedures
	Contingency planning	Airport crews can back up contractors if necessary, as they have experience and on-site equipment Common to have multiple concrete contractors doing work at the airport
	Material acceptance	PDR: None FDR (movement area): Compressive strength (4,000 psi at return to service) FDR (nonmovement area): No testing, requires 72-hour cure time

- Difficulty of closing runways at a large hub airport with only three runways;
- Need for mobilizing maintenance crews, which are not on-site, before nighttime emergency PDR can be started;
- Need for determining the location and extent of damage and for identifying the preferred repair method and material for nonemergency PDR; and
- Estimating concrete strength gain: PHX experimented with concrete maturity meter testing but discontinued its use because of cost concerns.

Key Takeaways

- Upfront planning is one of the most important elements for RSRR project success.
- Establish standard operating procedures for emergency PDRs, to include criteria for repair, and provide guidance on material selection based on repair depth, type of repair, and conditions. (PHX is working on this task. Similar procedures are being developed for nonemergency repair work.)
- Confirm existing conditions prior to slab removal. Concrete core samples can be taken for FDR to confirm concrete thickness and to understand the condition of sublayers (i.e., deteriorated or intact).
- Update as-constructed records when PDRs and FDRs are performed. This can be useful in tracking performance.
- Increase technical knowledge. PHX maintenance believes additional technical knowledge will help lead to the installation of longer-lasting PDRs and ensure the life of FDRs. This includes examples of other airport practices, case examples of projects, and even a national database that highlights what other airports do.
- Obtain local input. If available, technical input from a local agency (i.e., local city, county, state) can provide much-needed technical support related to the construction aspect of RSRR.

RSRR Practice at John Glenn Columbus International Airport

Overview

John Glenn Columbus International Airport (CMH) is a medium hub airport located in Columbus, Ohio. The airport has two parallel runways (Runway 10R-28L at 10,114 feet and Runway 10L-28R at 8,000 feet) with multiple parallel taxiways. CMH's PDRs are primarily performed by airport maintenance personnel. Table A-8 provides an overview of CMH's RSRR practice.

For rapid PDRs, CMH uses a proprietary, two-part polyurethane repair material on the basis of experience working with a local contractor. CMH has been using the material for several years, and it has worked well; the airport says the material is like other proprietary materials but seems to be more forgiving when the repair surface is being prepared under constrained time frames. The material is self-leveling, which helps with finishing, and can be extended with sand for deeper patch areas. Since the material sets very rapidly, crews can patch a spall and return the pavement to operation within 30 minutes. The airport has tried other materials but experienced some failures related to shrinkage. The airport operations department decides whether an emergency repair is needed (i.e., whether the area needs to be repaired in less than 8 hours) or whether the repair can be performed in a nonemergency manner. However, the same material is used for both. The maintenance personnel carry out planned (nonemergency) repairs as well as emergencies that arise.

RSRR Program Highlights

- **CMH uses site-specific material.** The airport has performed PDR for many years using different materials, repair details, and methods. The current patching material is not the most expensive material available, but airport personnel find it to be more forgiving in terms of preparation and ease of use, and it performs as well as the more expensive materials for the conditions at CMH. PDRs set quickly, allowing the facility to return to service in as little as 30 minutes, if needed. CMH has been using the material for 3 to 4 years and has had very few patches fail during this time.

Table A-8. Overview of RSRR practice at John Glenn Columbus International Airport.

Category	Item	Detail
Airport information	Airport location	Columbus, Ohio
	Owner	Columbus Regional Airport Authority
	FAA classification	Medium hub
	FAA region	Great Lakes
	LTPP climate region	Wet, freeze
	Number of runways	Two parallel
Planning	Stakeholder communications	Airport operations Weekly notices to airmen (NOTAMs) (routine PDR projects) Air traffic control tower and tenants (large PDR projects)
	Allowable closures	Variable, depending on facility and extent
	Funding	Airport
	Emergency work	PDR
	Project delivery	No information provided
	On-call contractors?	No information provided
Design	Designer	No information provided
	Design documents	No information provided
	Specification elements	Preparation and placement per manufacturer guidelines
Construction	Construction	PDR: Airport personnel FDR: Contractors
	PDR materials	Proprietary two-part polyurethane repair material
	FDR materials	No information provided
	Material testing	No information provided
	Construction inspection	No information provided
	QC/QA elements	No information provided
	Contingency planning	Weather monitoring, alternate operation routes
	Material acceptance	No information provided

- **CMH ensures that adequate resources are available.** The airport has maintenance personnel available 20 hours per day, with personnel on-call for the 4 hours without active employees. CMH can also draw personnel from Rickenbacker International Airport (part of the Columbus Regional Airport Authority's oversite), if needed. Creating a maintenance plan in the spring allows CMH to ensure adequate patching supplies are available.

Challenges

From the perspective of the maintenance personnel, the biggest challenges to carrying out successful PDR projects are as follows:

- Minimizing operational disruption: Although CMH has two parallel runways, one runway is longer than the other, and the airport works with the air carriers to do as much work as possible during daylight hours. The work on the longer runway can typically be performed from 8:00 a.m. to about 11:00 a.m. or noon, because a greater number of cargo operations are at night. Parallel taxiways and connectors typically allow alternate routes to maintain aircraft movements when work is required in areas of taxiways.
- Lack of maintenance personnel with FDR expertise: Airport staff do not perform larger repairs (slab replacement). Also, the material used for PDR is too costly to use for large FDRs.

However, maintenance crews have temporarily patched slabs needing replacement with this material. Contractors are then brought in to perform the FDR. Ongoing work has generally meant contractors are already on-site and available to be called on to place large repairs.

Key Takeaways

- Find the best material for airport conditions and needs. While CMH has tried more expensive proprietary materials for PDR, it is currently having success with a lower-cost proprietary material that maintenance personnel have found to be more forgiving for rapid repair. The material is easy to mix and place and sets quickly, which allows the facility to return to service in as little as 30 minutes.
- Take a proactive approach to internal maintenance work by conducting annual PDR assessments to plan work quantities.

RSRR Practice at Hartsfield–Jackson Atlanta International Airport

Overview

Hartsfield–Jackson Atlanta International Airport (ATL) is a large hub airport located in Atlanta, Georgia. ATL has built an effective and successful RSRR program over many years. PDR is the primary work performed, but FDRs are also periodically installed. Over the years, ATL has successfully used a portland cement–based mix. Repair details have been refined to help ensure success within limited closure times. Table A-9 provides an overview of ATL's RSRR practice.

Table A-9. Overview of RSRR practice at Hartsfield–Jackson Atlanta International Airport.

Category	Item	Detail
Airport information	Airport location	Atlanta, Georgia
	Owner	City of Atlanta, Department of Aviation
	FAA classification	Large hub
	FAA region	Southern
	LTPP climate region	Wet, nonfreeze
	Number of runways	Five parallel
Planning	Stakeholder communications	Air control tower Airlines Airport operations and security
	Allowable closures	PDR: 6- to 7-hour night closure FDR: 72-hour weekend closure
	Funding	Airport
	Project delivery	Design–bid–build
Design	Designer	Consultant
	Design documents	Plans and specifications
	Specification elements	Liquidated damages for exceeding closure windows Requires backup equipment and weather contingency plan
Construction	Construction	Prequalified contractors
	PDR and FDR materials	Portland cement–based, HES, some earlier trials of proprietary rapid-set materials
	QC/QA elements	Concrete testing: Air content, slump, flexural strength, and maturity
	Contingency planning	Redundant equipment, weather plan

RSRRs at ATL are often performed on pavements that are nearing planned major rehabilitation; therefore, a complete record of repair performance is not maintained. However, the PDRs generally last at least 5 years. Failures that have occurred are often the result of poor construction practices, such as materials placed when the ambient temperatures are too high or excessive paste has worked to the surface. ATL does monitor repair work through its 3-year pavement management updates.

RSRR Program Highlights

- **Building on past experiences helps ATL ensure success.** RSRR has been performed for many years at ATL with different materials, repair details, and methods. As a result, there is a knowledge base of what can and cannot be accomplished. Current materials and details have proven successful. While ATL has tried proprietary materials in the past, it is currently having success with a portland cement–based material (high cement content). ATL also has a reinforced PDR detail that has proven successful. The detail includes a horizontal reinforcing steel mat that is anchored to the adjacent sound concrete by tie bars. This repair detail has given ATL an effective means of addressing slab spalling.
- **The design–bid–build process is used to deliver RSRR projects.** During the design process, extensive coordination with stakeholders is conducted to identify closure times and access routes.
- **A dedicated gate is provided for construction.** The contractor covers the cost of additional security personnel.
- **The batch plant is located directly outside of the gate to shorten haul times.** Haul routes are planned with input from the airport operations group and air traffic control tower. The haul routes are driven prior to the work to make sure materials can get to the job site within the time constraints.

Challenges

From the perspective of the consulting engineer, the biggest challenges at ATL include the following:

- Very heavy airport operations that necessitate a significant effort to coordinate closures and haul routes and
- Lack of contractor experience with expedited methods and materials.

Key Takeaways

- Develop airport-specific material specifications and PDR details that work.
- Plan site access and movement across the airfield well in advance. ATL dedicates a construction gate for this work, and the contractor provides additional security personnel for the gate as part of the contract.
- Schedule work during periods with historically better weather. ATL generally tries to have this work performed from September through November on the basis of historical weather trends. Weather days are built into the construction schedule, particularly if construction occurs during other times of the year.
- Select contractors that have good experience with early-strength materials and working in a congested airfield environment. At ATL, test areas are used to ensure the contractor is familiar with the materials.

RSRR Practice at Louisville Muhammad Ali International Airport

Overview

Louisville Muhammad Ali International Airport (SDF) is a small hub airport located in Louisville, Kentucky. SDF's airside pavements are primarily concrete. There are three concrete runways, two of which are parallel and one a crosswind. Runway 17R-35L is the longest of the three, at 11,890 feet long, and Runway 17L-35R is 8,580 feet long. In addition to commercial and Air National Guard operations, the airport serves as a United Parcel Service Worldport. With the heavy volume of cargo operations, maintaining operational pavement is essential.

FDR needs are determined by regular visual inspection. Cracking and spalling are major drivers triggering the need for slab replacement, and FDRs are identified and grouped into the next rehabilitation project. Table A-10 provides an overview of SDF's RSRR practice.

Replacement of the large slabs (25 by 25 feet by 17 inches thick) on Runway 17R-35L started in 2009 and is conducted at least annually (in some years there have been two projects). When the airport started these projects, there were some pretty bad conditions, including shattered slabs. SDF also experienced the "zipper effect," in which a cracked slab, if left unrepaired, would affect

Table A-10. Overview of RSRR practice at Louisville Muhammad Ali International Airport.

Category	Item	Detail
Airport information	Airport location	Louisville, Kentucky
	Owner	Louisville Regional Airport Authority
	FAA classification	Small hub
	FAA region	Southern
	LTPP climate region	Wet, nonfreeze
	Number of runways	Two parallel, one crosswind
Planning	Stakeholder communications	Air control tower Airlines Airport operations and security
	Allowable closures	56.5-hour (weekend) closure for runways
	Funding	FAA and entitlements
	Project delivery	Design–bid–build
Design	Designer	Consultant
	Design documents	Plans and specifications
	Specification elements	Liquidated damages for exceeding closure windows Requires backup equipment, weather contingency plan, and so forth
	In-pavement lights	Some slabs
Construction	Construction	Prequalified contractors
	FDR materials	Portland cement–based, conventional and MES
	Contractor QC	Testing firm
	Construction inspection	Consultant
	QC/QA elements	Concrete testing: Air content, slump, flexural strength, and maturity
	Contingency planning	Redundant equipment, weather plan
	Material acceptance	Flexural strength and thickness

adjacent slabs within a short time. The airport considered alternatives, including cross-stitching, but has primarily performed FDRs.

FDR work is done with a portland cement–based MES mixture, but only where early strength gain is needed, which is primarily on the runway or in critical areas such as intersections where cargo carriers need access. In SDF's experience, the MES achieves 550 psi compressive strength in 30 hours. However, the mix is difficult to work with ("sticky") and is very volatile. For example, during the summer, mixes arrive at or near 90°F, which is close to a temperature at which the mix will flash set. During placement, several technicians are on-site for mix acceptance testing. When trucks arrive on-site, they have about 20 minutes for placement, with a total period of typically 60 minutes from time of batching to time of placement. On the taxiways, which allow 14-day closures, the use of MES is not required, and 550 psi is achieved in 7 days with a standard portland cement–based concrete mix.

FDR projects are generally carried out during short closure windows, as there is little availability for long-term closures because of significant cargo operations. A typical schedule includes a 7.5-hour Friday closure for preparation (sawing), followed by the primary runway closure from Saturday to Monday afternoon. Taxiway slab repairs are performed under longer closures.

Contracts for rapid repairs include liquidated damages, which vary in amount, depending on the location of the repair: $500 per day for areas with minimal impact, $1,000 per day for taxiways, and $5,000 per hour or portion thereof for runways.

RSRR Program Highlights

- **Building on past experiences has helped SDF refine its program.** Achieving the required strength was a big concern during the first year of the airport's FDR program. However, the project specifications did not have an upper limit on strength, and during that first year, the concrete gained strength too rapidly and developed microcracking. For the next year's FDR contract, SDF implemented an upper strength limit (1,200 psi at 28 days), which improved results. While contractors first resisted this upper limit, it has since become standard procedure, and local suppliers have learned how to use their additives to achieve the requirements. ATL has also changed how it handles light cans. Initially, the contractor had the option of putting in light cans during FDR or using a two-stage process in which the contractor would come back the next week to perform coring and replacement. Use of the two-stage process resulted in cracking, and, consequently, that process is no longer allowed.
- **The design team uses contingency planning to manage risk during construction.** In case of the need for an emergency reopening, temporary precast slabs are constructed that can be placed in the FDRs.
- **Each project includes substantial stakeholder coordination.** Early project meetings involve coordination with a variety of stakeholders, from the escorts to the material testing to the go/no-go meeting with airlines. A preconstruction meeting is held with contractors, producers, truckers, and others. This meeting gets everyone to agree on the means and methods associated with the production and placement of the materials. Weekly go/no-go meetings are conducted with the cargo carrier, which has access to excellent weather-forecasting tools; even if conditions look good on Friday and Saturday, scheduled construction is usually called off if there is a chance of rain on Sunday. A daily pour agreement meeting is also conducted. The operations department is responsible for communication and coordination with the commercial and cargo airlines. The contractor is always included, and the companies that do these projects have experience with coordination. SDF operations puts out barricades and sends out a notice to airmen (NOTAM) showing barricade locations.

Challenges

From the perspective of the consulting engineer, the biggest challenges at SDF are as follows:

- Closure decisions based on cargo carrier input,
- Significant coordination of closures and haul routes, and
- Need for contractors and materials suppliers familiar with VHES concrete.

Key Takeaways

- Protect the surrounding slabs during saw cutting. SDF has used a steel plate along the adjacent slab as one method of preventing oversawing. Because friction during removal can cause spalling in the adjacent remaining pavement, a piece of laminate is placed in the saw cut to reduce friction. A sawing pattern is used in which a cut is made 1 foot in from the joint to facilitate removal and minimize the risk of damage to adjacent pavement. Sawing near cracks is avoided (the pattern being adjusted on each slab) to minimize the risk of FOD between closures. Finally, interior cuts are angled so that pieces can be more easily lifted out. Sawing is typically performed in a shorter closure (1 to 2 days) prior to removal. On one occasion, sawing was allowed a week in advance, and the ensuing traffic significantly damaged the saw cut slab.
- Remove saw slurry to keep the facility in service. SDF has turned to both maintenance and ARFF personnel to help clean up. These departments can mobilize equipment that the contractor cannot when there is an urgent need.
- Conduct green sawing at the proper time to control cracking. There have also been past issues with the ability to saw in a straight line, which can cause thousands of dollars of rework.

RSRR Practice at Raleigh–Durham International Airport

Overview

Raleigh–Durham International Airport (RDU) is a medium hub airport located in Morrisville, North Carolina. RDU has three runways: two parallel runways and a crosswind. Runway 5L-23R is a 10,000-foot concrete facility that serves as RDU's primary runway. Runway 5R-23L is 7,500 feet and is currently overlaid with asphalt.

Runway 5L-23R was originally constructed in 1986 as a jointed concrete pavement, and much of the original pavement is still in place. However, alkali–silica reaction began appearing around 2002 and has caused ongoing deterioration and the need for repairs. Some patching and joint sealing were performed in 2003 and 2004, and those patches have performed relatively well. However, after a few wet winters, deterioration on the runway accelerated. As a result, the airport undertook a multiyear pavement repair project beginning in 2019. During 2019, the airport replaced 117 slabs (25 by 25 feet by 16 inches thick) between the spring and fall during day-long runway closures. While it was planning to do the same in 2020, it instead had a 40-day COVID-19-related closure and was able to replace another 108 slabs. Table A-11 provides an overview of RDU's RSRR practice.

For this project, the contractor fabricated some precast slabs for emergency use. The airport viewed these as a last resort and did not want the contractor to feel it could depend on them. The precast slabs were not needed, as no disruptions occurred, although the contractor had to demonstrate that it could place the precast slabs by practicing on an apron.

The contract for the 2019 project incorporated liquidated damages of \$100 per minute. This was intended to focus attention on the need for immediate opening at the specified time rather

Table A-11. Overview of RSRR practice at Raleigh–Durham International Airport.

Category	Item	Detail
Airport information	Airport location	Morrisville, North Carolina
	Owner	Raleigh–Durham Airport Authority
	FAA classification	Medium hub
	FAA region	Southern
	LTPP climate region	Wet, nonfreeze
	Number of runways	Two parallel, one crosswind
Planning	Stakeholder communications	Air control tower Airlines Airport operations and security
	Allowable closures	18- to 22-hour closures for runways
	Funding	Airport
	Project delivery	Design–bid–build, construction manager at-risk
Design	Designer	Consultant
	Design documents	Plans and specifications
	Specification elements	Liquidated damages for exceeding closure windows Requires backup equipment, weather contingency plan, and so forth
	In-pavement lights	Some slabs
Construction	Construction	Prequalified contractors
	FDR materials	Portland cement–based, HES; some earlier trials of proprietary rapid-set materials
	Contractor QC	Testing firm
	Construction inspection	Consultant
	QC/QA elements	Concrete testing: Air content, slump, flexural strength, and maturity
	Contingency planning	Redundant equipment, weather plan
	Material acceptance	Flexural strength and thickness

than in larger increments of quarter or full hours past the opening time. Damages were capped at $36,000 to allay contractor concerns and increase the number that bid on the project. In the end, the runway repair work was bundled with an apron project to ensure contractors would bid on the work.

RSRR Program Highlights

- **RDU utilizes pavement management to track deterioration and identify repair needs.** RDU has been monitoring and mapping distresses and collecting PCI and deflection data, which it has incorporated in computer-aided drafting software maps to track conditions and make decisions. RDU determined the pavement was losing about 4 PCI points per year, which is a high rate for the airport. It also observed an increasing rate of full-depth cracking in recent years, and the 23R end of the runway seemed to have saturated subgrade, which was associated with poorer performance than the 5L end.
- **It can be beneficial to have a construction manager at risk onboard (for a large-scale RSRR project) to answer questions during planning.** An experienced construction manager can make decisions about RSRR materials, accepting or rejecting concrete loads, weather conditions, and project coordination, among other things. The importance of effective communication cannot be overemphasized.

Challenges

- Coordination of airline operations: Coordinating closures is a significant effort. The team obtained airline input early and offered either one extended closure or multiple daily closures to complete the work. The airlines chose the daily closures (on the basis of accommodating flight schedules) and were engaged stakeholders from the beginning. Personnel also kept stakeholders informed with monthly meetings. The determination of the allowable closure time frame is a balance between construction efficiency and operational efficiency.
- Dealing with in-pavement lights in FDR projects: The lights are hard to replace within the 18- to 22-hour closure. RDU's solution is to keep the lights in place by coring or saw cutting around them, chipping concrete off the cans, and then placing new concrete around the existing cans. It was also planned to have no more than three lights out at a time. This process worked well for slabs with light cans, and no lights were out during the repairs. Additional cans were available on-site in case they were needed for replacement.

Key Takeaways

- Develop repair material specifications that meet, but do not significantly exceed, strength-gain requirements. The concrete mix (developed by contractor) was specific to this project, but RDU had previously used similar materials. It wanted to avoid ASTM C150 Type III cement due to concerns about early cracking. The contractor needed to be convinced time constraints could be met with the use of a mix with a cement content of less than 800 pounds per square yard, which was achieved. The contractor did a lot of on-site practice under a range of simulated real-world conditions to gain confidence it could meet project requirements. The process of finding a concrete mix that would work took 3 to 4 months. The airport anticipates 8 to 10 years of performance before total reconstruction but has no reason to believe the FDRs could not last much longer. None of the 2019 slabs has failed; there were also no failures among the 2020 slabs, but the work was not performed with the same closure constraints.
- Perform sawing the night before beginning the project; use wood shims in the cracks to keep the slabs from moving and causing spalls that create FOD.
- Use maturity meters to better target break times for determining the time for opening to traffic.
- Postpone work if poor weather is forecast. Include a line item in the contract to cover the situation in which a contractor mobilizes but then cannot not perform the work.

APPENDIX B

Examples of Rapid Slab Repair and Replacement Projects

This appendix provides examples of RSRR projects and lessons learned from visiting construction sites and discussions with contractor personnel, construction inspectors, and airport personnel. Each case example provides the following with respect to RSRR practice at each featured airport:

- Project overview,
- Construction observations, and
- Discussion.

Table B-1 lists the examples of RSRR projects. The examples are arranged from west to east and according to FAA region and associated LTPP climate region (FHWA 2016).

Full-Depth Repair at San Francisco International Airport

Project Overview

The project at San Francisco International Airport (SFO) project consisted of replacing nine 25- by 25-foot concrete slabs (5,625 square feet) that were exhibiting midpanel and corner cracking. The slabs serve as an engine startup pad for wide-body aircraft and are located on a taxilane that serves Concourses A and B. The startup pad was originally constructed in August 2017, and cracking was observed in some of the slabs a few weeks after construction. Airfield operations had discussed replacing these slabs, but the work was postponed until 2020 because of construction on the adjacent Concourse B. Since 2017, the airport has monitored the panels and performed small slab repairs as needed. In 2020, the airport was able to conduct the FDRs as a change order to an existing FDR project on an adjacent concourse. This allowed the project to be quickly executed, and the on-site contractor and design team were able to produce plan sheets and details. It also allowed the use of a concrete mixture from the adjacent construction project, with minor modifications.

The construction process included removal of the damaged concrete and base reconstruction. Stakeholder coordination began 2 months before construction and involved weekly meetings with approximately 30 people. Effective stakeholder communication and coordination allowed the engine startup pad to be closed to aircraft operations for a continuous 30-day period, which was accomplished by using temporary taxilanes and vehicle service roads to steer traffic around the closure. This allowed the contractor to replace multiple slabs in the same construction sequence with an HES, fiber-modified P-501 concrete mixture, which was deemed a more practical mixture than the VHES mixtures typically used for overnight closures. Figure B-1 shows the project location on the airfield.

Table B-1. Examples of RSRR projects.

Airport	FAA Region	LTPP Climate Region	RSRR Type
San Francisco International	Northwest Mountain	Wet, nonfreeze	FDR
Seattle–Tacoma International	Northwest Mountain	Wet, nonfreeze	FDR
Phoenix Sky Harbor International	Western Pacific	Dry, nonfreeze	PDR/FDR
Gerald R. Ford International	Great Lakes	Wet, freeze	PDR
Cincinnati/Northern Kentucky International	Southern	Wet, freeze	PDR/FDR

Figure B-2 shows the concrete finishing operation and a finished slab ready for curing compound.

Table B-2 provides general information about this project.

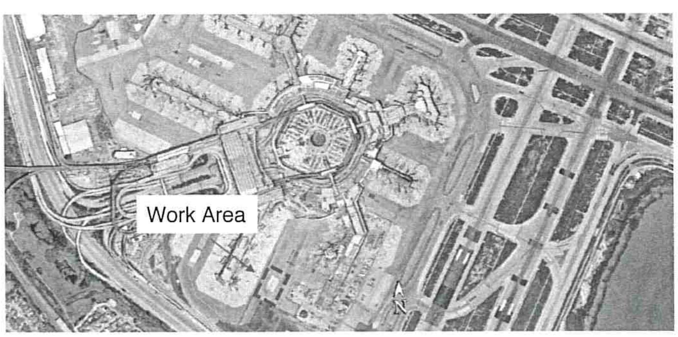
Construction Observations

Demolition

The slab perimeter was saw cut at least 1 day prior to slab removal. The construction time frame permitted the use of the breakup and removal method. The contractor used two excavators with jackhammer attachments to break the slabs into pieces, which were removed by another excavator. The on-site engineer reported no damage to adjacent slabs. The existing base and subbase layers were also removed in preparation for the new pavement section. During demolition, the exposed subgrade surface was saturated with rainwater, which required the removal of an additional 6 inches of subgrade material prior to the rebuilding of the pavement structure.

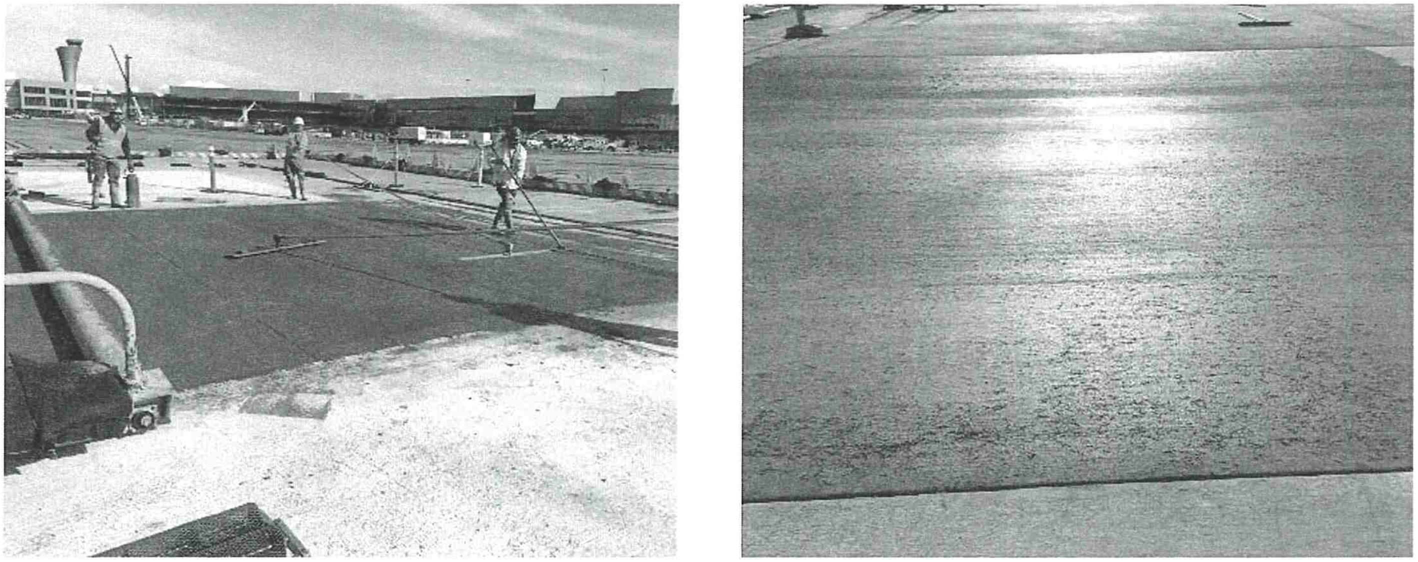
Preparation

The exposed subgrade material was recompacted to 95% compaction (a nuclear gauge was used to verify density). According to project drawings, a Class II, nonwoven, medium-weight fabric was placed on the existing subgrade followed by a geogrid. A 12-inch-thick P-219 recycled concrete aggregate base course was installed, followed by a 5-inch P-306 lean concrete base layer (see Figure B-3). The surface layer was a 21-inch HES P-501 portland cement concrete



Source: Google, n.d.

Figure B-1. Project location at San Francisco International Airport.



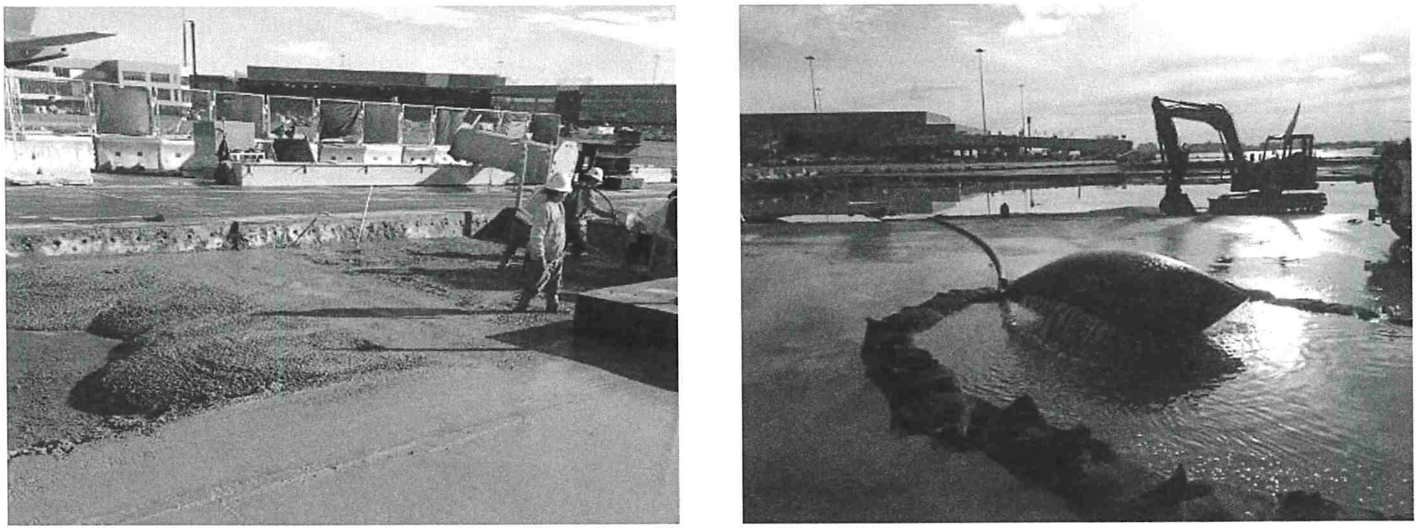
(a) (b)

Source: Nichols Consulting Engineers, Chtd.

Figure B-2. Example of cast-in-place full-depth repair at SFO: (a) finishing after placement and (b) finished texture.

Table B-2. General information: Project at San Francisco International Airport.

Category	Detail
Airport location	San Francisco, California
Owner	City and County of San Francisco
FAA classification	Large hub
FAA region	Western Pacific
LTPP climate region	Wet, nonfreeze
Facility and location of work	Taxilane between Concourses A and B
Closure Time	30 days
Type of work	FDR
Dates of construction	January 7–30, 2020
Site visit weather conditions	Temperature: 50°F to 55°F Humidity: 80% Wind: <5 mph Sunny, rained before paving and contractor had to drain site
Work performed by	Contractor
Construction drawings and specifications?	Yes
Emergency work?	No, but the airport wanted to get the work done expeditiously



(a) (b)

Source: Nichols Consulting Engineers, Chtd.

Figure B-3. Preparation at SFO: (a) placement of lean concrete base course and (b) rainwater removal.

with synthetic macrofibers and microfibers and steel reinforcement. FDRs were not performed during a single overnight or daytime closure and, consequently, the contractor needed a contingency plan to remove rainwater from the construction site. This was done by using pumps with installed sedimentation control measures; an example from an adjacent work area is shown in Figure B-3.

Load-Transfer Restoration

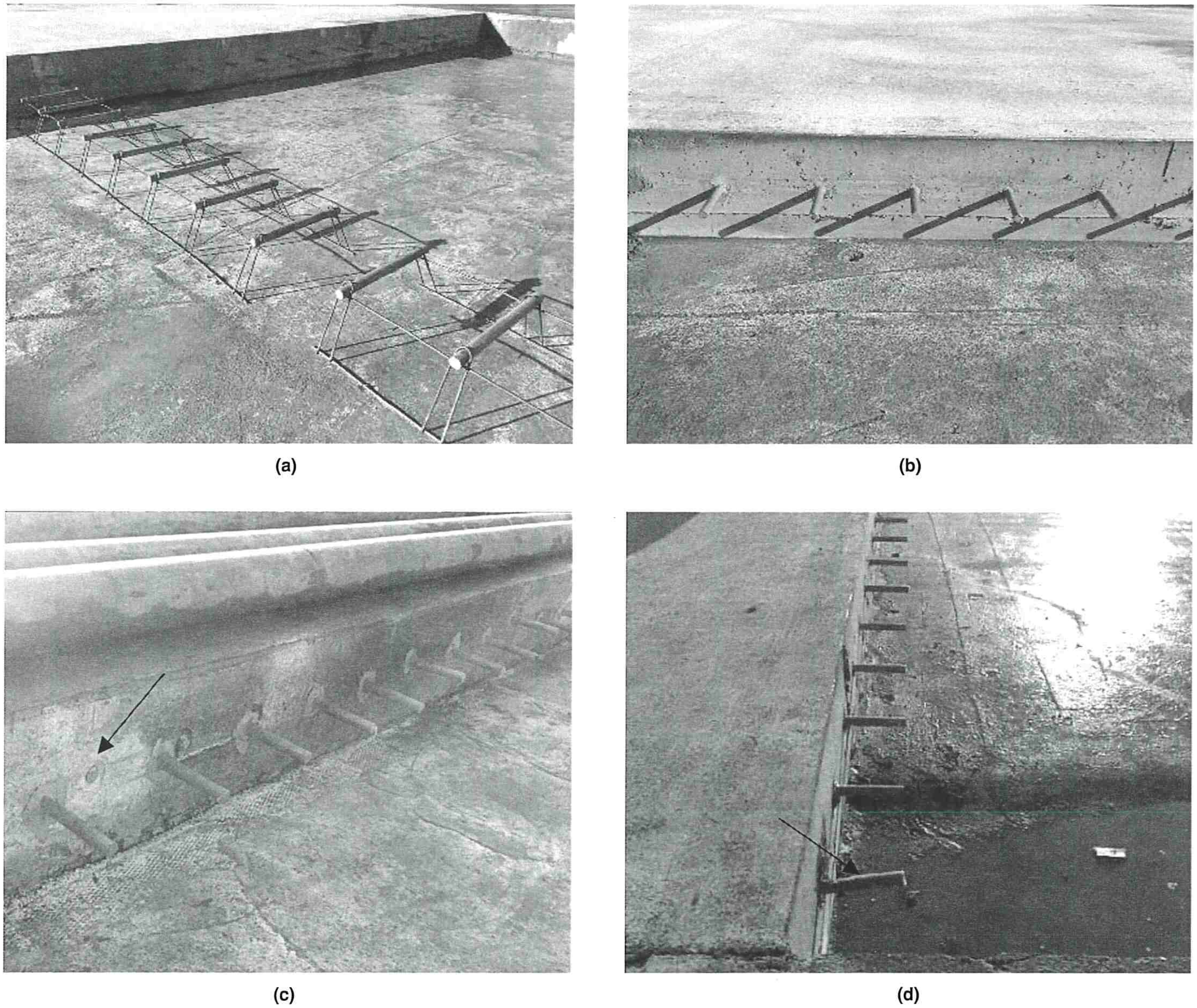
Dowel bars were placed at transverse joints and at slab edges abutting existing concrete. The 1.5-inch-diameter epoxy-coated dowels were 20 inches long and spaced 18 inches on center. Dowel bar baskets were used for transverse contraction joints. For construction joints, a gang drill was used to simultaneously drill two or three dowel bar holes at a diameter of ⅛ inch greater than the diameter of the dowels. Dowels at the corners of slabs were hand drilled, which resulted in misaligned dowel bars in some instances. Plans called for drilled dowels to be a minimum of 3 inches from the old dowel bars, which were cut off and remained in the existing concrete. The drilled holes were cleaned by means of compressed air, and the dowels were anchored into the holes with two-part paste epoxy (but without retention disks). Figure B-4 shows installed dowel bars.

Concrete Mixture

The contractor used a 6,000 psi (compressive) HES P-501 concrete with an added blend of synthetic macrofibers and microfibers (combined dosage of 5 pounds per cubic yard) for shrinkage and secondary reinforcement. The design properties and mix proportions of the concrete mixture are summarized in Table B-3 and Table B-4, respectively.

Concrete Placement

The concrete was mixed and delivered to the site in ready-mix trucks. The concrete mix was very flowable, with slump measurements ranging from 6.5 to 7.0 inches. To ensure proper placement, concrete was pumped into place at a rate of 1 to 2 cubic yards per minute. Consolidation was done with a stinger vibrator and by hand using shovels. Ready-mix trucks fed the concrete pump



Source: Nichols Consulting Engineers, Chtd.

Figure B-4. Installed dowel bars at SFO: (a) dowel bar assembly for contraction joints, (b) dowel bars as a construction joint, (c) dowel bars offset from cut dowel bars, and (d) misaligned dowel bar.

Table B-3. Design properties of SFO concrete mixture.

Property	Typical Value
Compressive strength (psi) at 28 days	6,000
Specified slump (in.)	6 to 7
Design air (%)	2.0
w/cm ratio	0.33

Table B-4. Proportions of concrete mixture used in SFO project.

Materials	ASTM	Proportion per yd³ Weight (lb)	Volume (ft³)
Fine Aggregate 1	C33	895	5.47
Fine Aggregate 2	C33	407	2.35
Coarse Aggregate #57	C33	1,375	7.65
Coarse Aggregate #7	C33	500	2.78
Type II/V cement	C150	799	4.06
Class F fly ash	—	—	—
Potable water	C1602	267	4.28
Air content			0.54
Total			27.13

Note: Admixtures (optional—to be added upon request):
- ASTM C494 Type B and D 2 to 6
- ASTM C494 Type C 10 to 45

truck, which placed concrete to half the slab depth. Concrete was consolidated, and then the reinforcing steel mesh was placed. The remainder of the concrete was placed and consolidated, and a power screed was used to level the slab surface and establish the final grade.

Figure B-5 illustrates the concrete placement procedure.

Finishing and Curing. A roller tamper was used to depress coarse aggregate and to achieve a more uniform surface finish. The finishing process continued with the use of bull floats and a broom finish. A water-and-wax-based, white-pigmented curing compound was applied after finishing. Figure B-6 shows the steps for finishing, texturing, and curing.

Joints. A lightweight saw was used to create 0.25-inch-wide by 4-inch-deep contraction joints as soon as the slabs were deemed solid enough to minimize spalling. Joints were later cut to a final depth of 7 inches, equivalent to ⅓ of the slab depth (Figure B-7).

Material Testing

The HES concrete was required to have a flexural strength of at least 650 psi at the time it was returned to service. This was not a concern given the 7-day cure time and total 30-day closure time allotted to complete the FDRs.

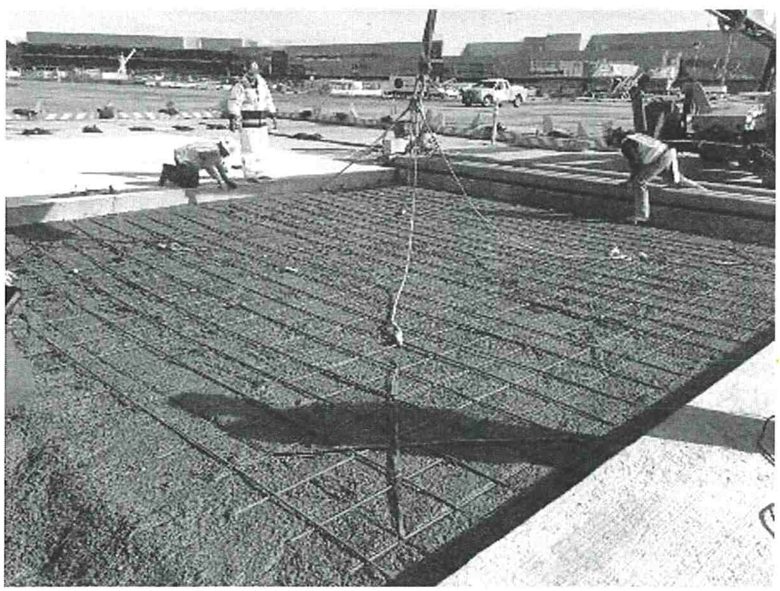
Discussion

Observation of the construction of the FDRs provided the following insights. These observations were supplemented by on-site discussions with contractor and airport personnel, along with follow-up correspondence.

- **Advanced coordination with all stakeholders was paramount to successful delivery of the airfield slab replacement.** Stakeholder coordination began 2 months before construction and involved weekly meetings with approximately 30 people. Some of the critical components that made this project a success were good communication and coordination with stakeholders to schedule and carry out the taxilane closure. The longer closure time allowed the contractor to maximize efficiency in slab placement and not be burdened with having to cut,

(a)

(b)



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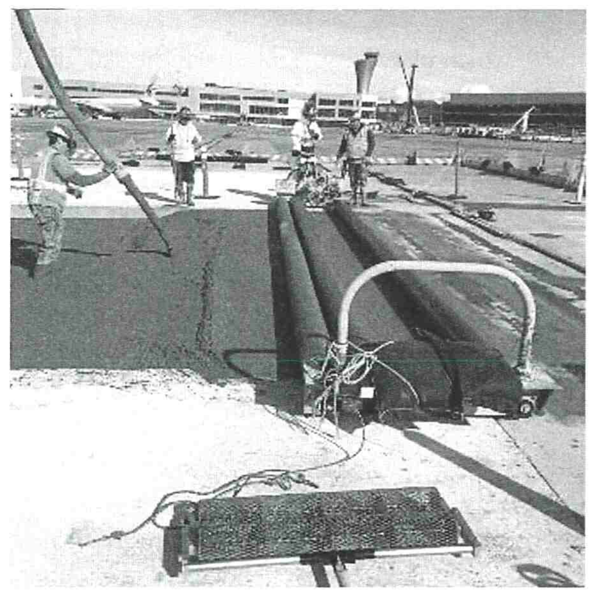


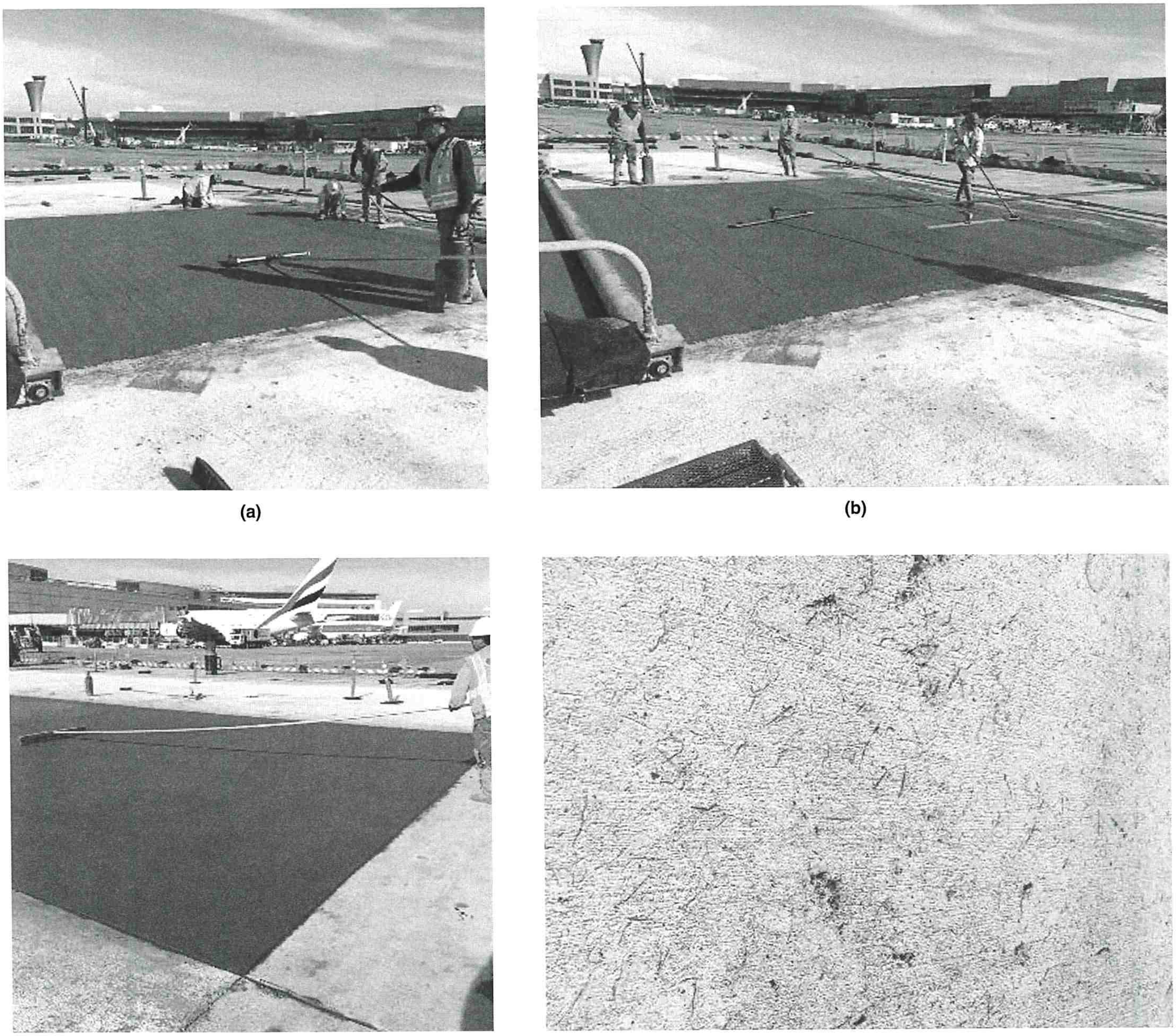
(d)

Source: Nichols Consulting Engineers, Chtd.

Figure B-5. Concrete placement sequence in SFO project: (a) placing concrete, (b) placing and consolidating concrete at dowel bar assemblies, (c) installing reinforcing steel, and (d) screeding concrete.

remove, and replace one or two slabs per night, which would have been the case if the work had been completed in multiple nighttime closures. The continuous placement of multiple rows of slabs also improved construction quality and will likely contribute to a longer-lasting product.

- **Use of an existing design team and on-site contractor accelerated the overall slab replacement process.** A design team and contractor were already on-site replacing concrete slabs at the adjacent boarding areas. The airport executed a change order to the existing contract that significantly shortened project delivery. The design team was able to prepare a single plan sheet modification to the boarding area construction plans, and the contractor was able to



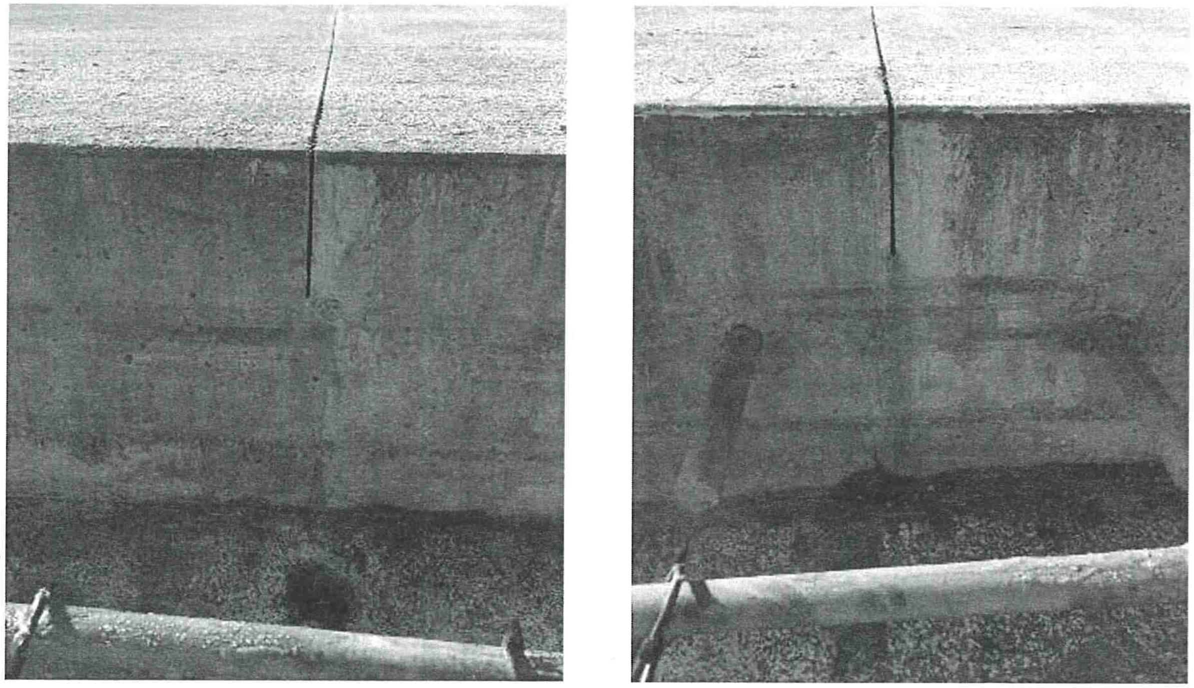
(a) (b) (c) (d)

Source: Nichols Consulting Engineers, Chtd.

Figure B-6. Concrete surface finishing, texturing, and curing in SFO project: (a) roller tamping, (b) surface finishing and edging, (c) broom finishing, and (d) surface with curing compound (macrofibers are present in the finished surface).

quickly schedule and execute construction. The crews were familiar with the existing site conditions, had the necessary security badges, were familiar with the slab replacement process, and had experience working with the HES concrete mixtures.

- **Safety and security required a significant commitment of airport personnel**. Barricades surrounded the working areas—both portland cement concrete and asphalt replacement—and on the closed portion of the taxilane. Airport operations vehicles continuously secured all work areas. The contractor and airport coordinated in advance so that plenty of airport operations personnel were on-site to provide escort for construction activities.



Source: Nichols Consulting Engineers, Chtd.

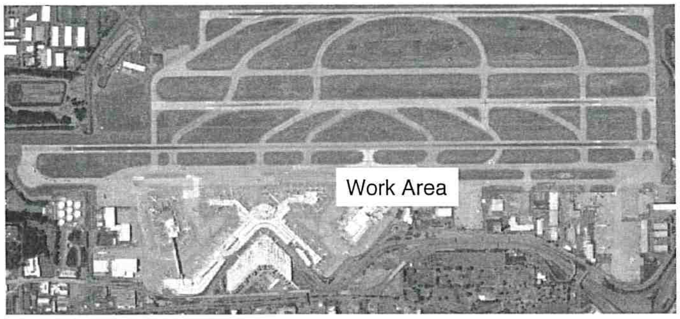
Figure B-7. Contraction joint saw cuts in SFO project.

- **Proper use of personal protection equipment (PPE) was essential for both contractor and airport employees.** This was most evident when the contractor was air-blasting holes for dowel cleaning and for mixing two-part epoxy for dowel anchoring.
- **The concrete mixture was reviewed by the airport's pavement consultant, who advised the contractor to add synthetic microfibers and macrofibers.** The concrete mix was delivered on time and met the specifications for consistency and compressive strength. Since the air temperature was in the low 50s (°F), a nonchloride accelerator admixture was used in the concrete mixture.
- **Providing the contractor with a secured area in which to work enabled the paving to be completed well ahead of schedule.** The contractor was able to mobilize the sawing and slab removal operations on a large scale. This also allowed sufficient staging of concrete trucks, which successfully delivered up to 120 cubic yards of concrete to place three slabs per day.

Full-Depth Repair at Seattle–Tacoma International Airport

Project Overview

This nonemergency project was carried out to replace three concrete apron slabs at commercial gate D11, where the existing slabs were demolished and replaced with VHES concrete. Originally, a single 9-hour daytime closure (8:00 a.m. to 5:00 p.m.) was allotted for FDR. However, during slab removal, an unexpected pipe was uncovered, which required an additional 9-hour closure the following day for removal. Figure B-8 provides an overview of the project location, and Table B-5 provides general information for this project.



Source: Google, n.d.

Figure B-8. Project location at Seattle–Tacoma International Airport.

Construction Observations

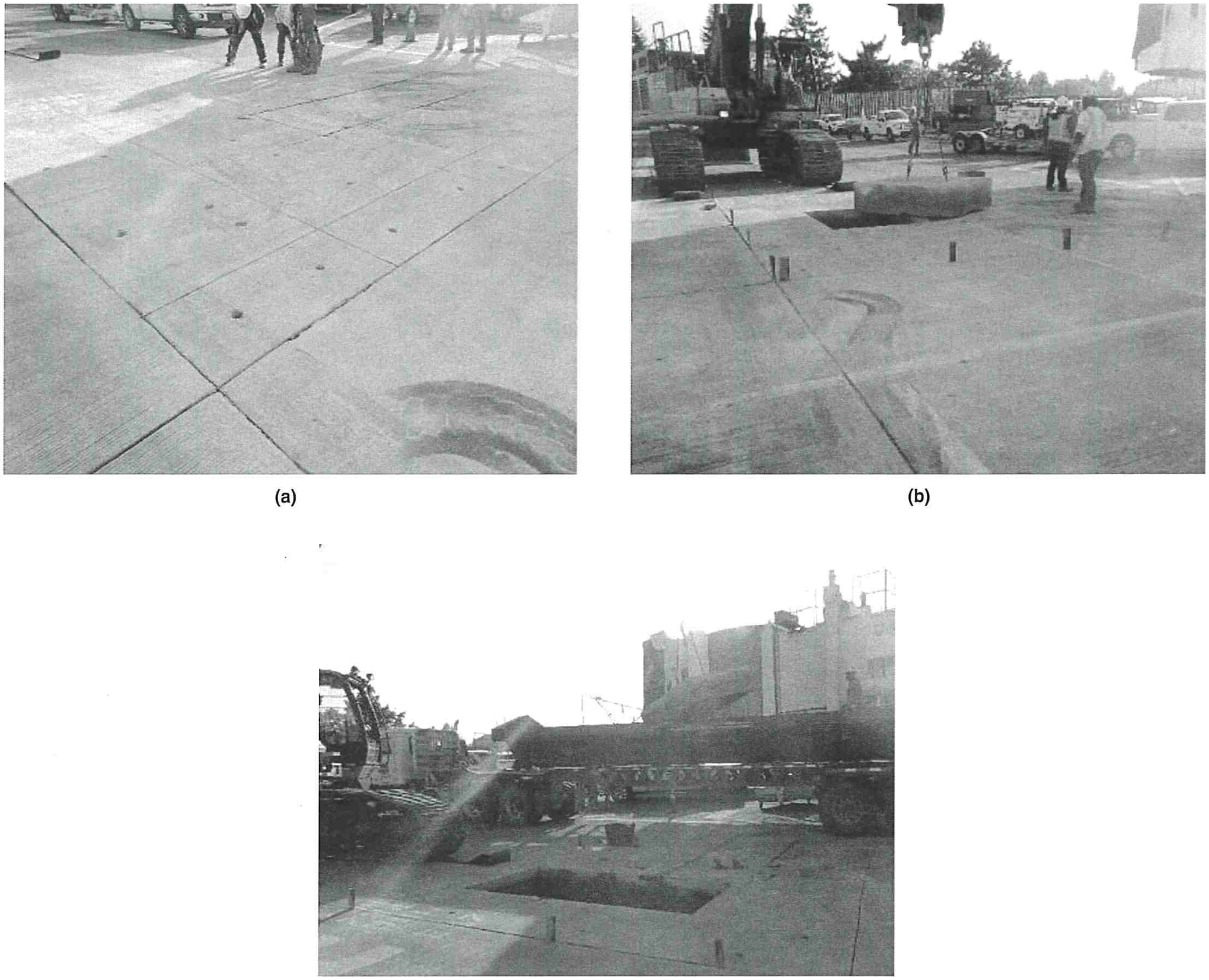
Demolition

SEA inspectors had previously identified three slabs for replacement under an accelerated construction schedule. The slabs were cut into approximately 20 pieces with a concrete saw the day before scheduled construction. Two expanding lift anchors were pounded into holes drilled into each piece, followed by lift-out with an excavator. Figure B-9 provides images of the slab removal process. The slab was saw cut into smaller pieces, and holes were drilled for lifting pins. Next, wood wedges were driven into the saw cut joint around the slab to be removed to help prevent damage to adjacent concrete during the lift-out process. Finally, the pieces were lifted.

During demolition, a portion of the slab being removed was found to be heavily reinforced. The contractor tried several methods to remove these pieces but ultimately used a hydraulic

Table B-5. General information: Project at Seattle–Tacoma International Airport.

Category	Detail
Airport location	Seattle, Washington
Owner	Port of Seattle
FAA classification	Large hub
FAA region	Northwest Mountain
LTPP climate region	Wet, nonfreeze
Facility and location of work	Apron area at commercial gate D11
Closure time	Daytime (8:00 a.m. to 5:00 p.m.)
Type of work	FDR
Dates of construction	September 25–26, 2019
Site visit weather conditions	Temperature: 60°F to 68°F Humidity: 60% to 75% Wind: 5–8 mph Cloudy sky
Work performed by	Contractor
Construction drawings and specifications?	No
Emergency work?	No



(a) (b) (c)

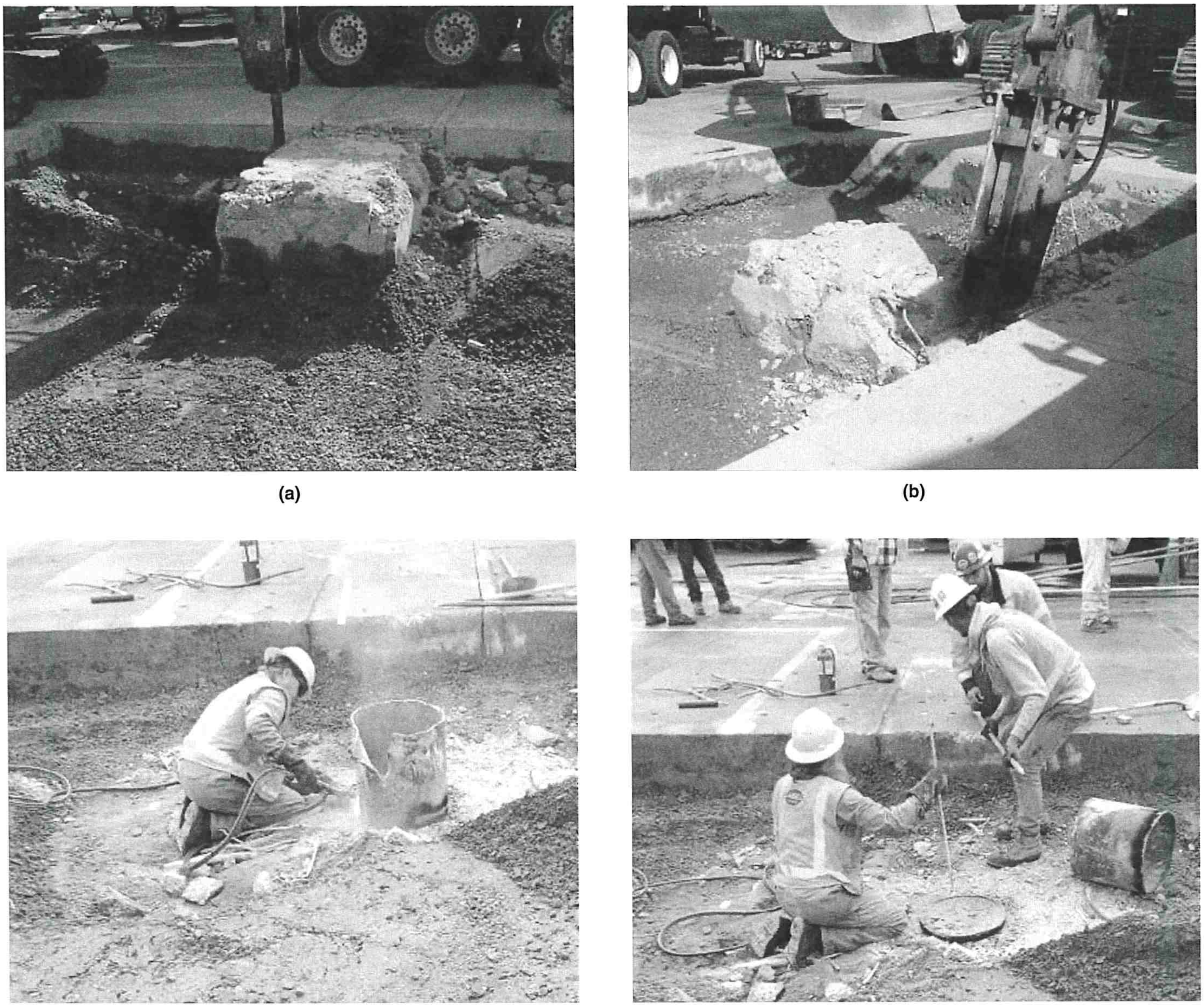
Source: Nichols Consulting Engineers, Chtd.

Figure B-9. Sequence of removal of existing cracked slab at SEA: (a) slab saw cut into pieces and holes drilled for lifting pins, (b) wooden wedges driven into joints to prevent damage to adjacent slabs, and (c) slabs lifted with an excavator and loaded onto a trailer.

breaker. The reinforced concrete was found to be a cap for an existing vertical steel tube. SEA inspectors were unable to determine the purpose of the abandoned pipe. The hydraulic breaker worked well, but demolition of this highly reinforced concrete turned out to be a time-consuming effort that took several hours. As a result, concrete placement was delayed until the next day, and the contractor backfilled the repair area with aggregate base and placed a steel plate over the aggregate. The removal process is shown in Figure B-10.

Preparation

After the pipe and surrounding concrete were removed, the base material was tested for chemical contaminants with a handheld electronic odor detector device. Contaminated base material would have been removed and replaced with new base material; however, contaminants



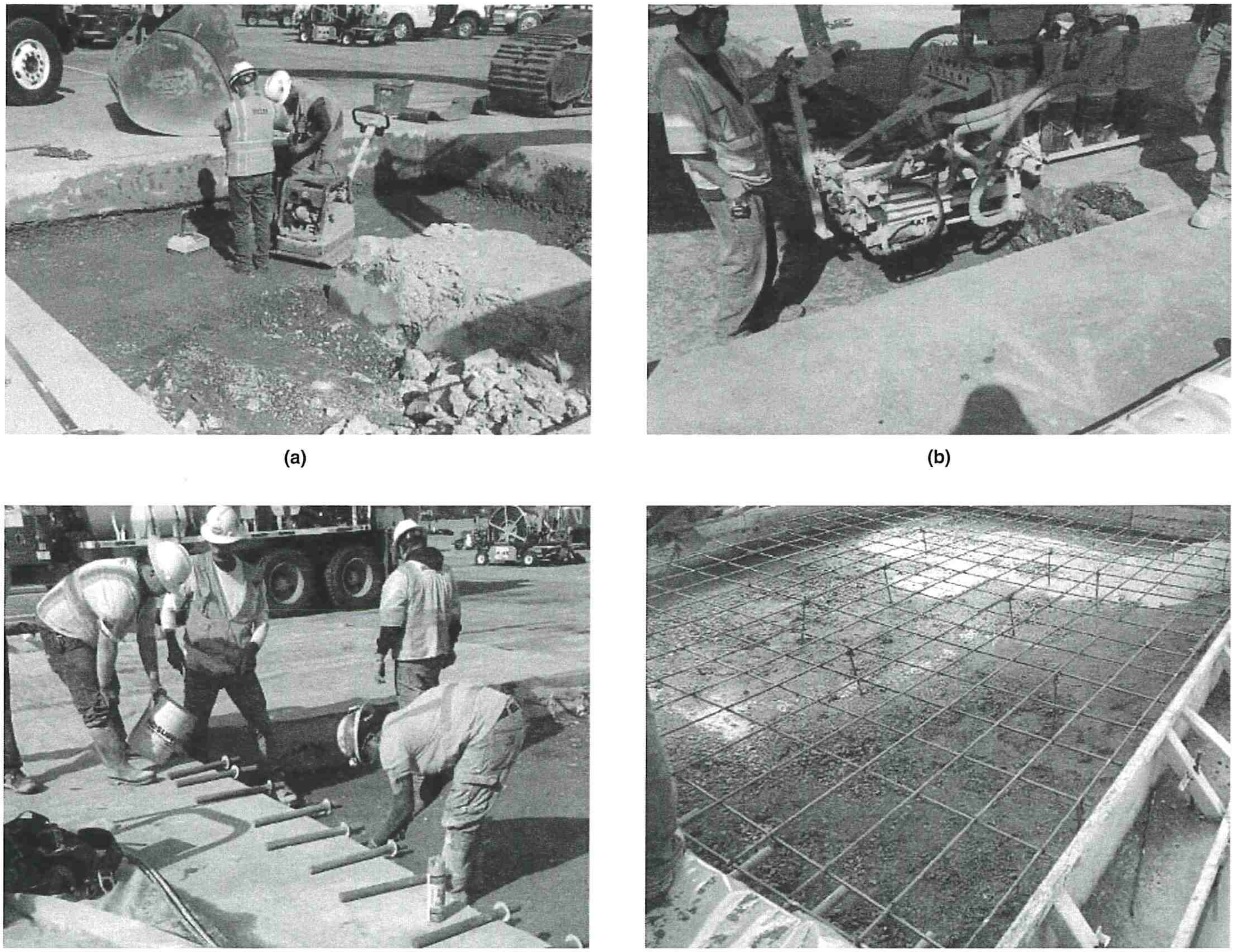
(a) (b) (c) (d)

Source: Nichols Consulting Engineers, Chtd.

Figure B-10. Removal of reinforced concrete portion and top of abandoned pipe at SEA: (a) existing condition, (b) demolition of concrete, (c) cutting of metal pipe, and (d) pipe removal completed.

were not detected. The existing base was leveled with the excavator bucket and compacted with a vibratory plate. Density testing with a nuclear gauge was performed, with a target of 100% compaction.

Dowel bars were installed along all four sides of each repair area. Holes were drilled into the existing slabs with a truck-mounted four-barrel drill. Several tubes of epoxy were squeezed into a bucket and mixed by using a drill with mixer attachment. Dowel bars were dipped into the mixed epoxy and slid into the drilled holes. Grout retention discs were installed over each dowel bar (against the slab) to prevent the epoxy from seeping out. A steel reinforcement mat was installed at slab middepth in all the repair areas. Sequential preparation of a repair area for concrete placement is shown in Figure B-11.



(a) (b) (c) (d)

Source: Nichols Consulting Engineers, Chtd.

Figure B-11. Preparation of repair area prior to concrete placement at SEA: (a) checking density, (b) drilling dowel bar holes, (c) dowel bar installation (note proper use of epoxy retention discs), and (d) reinforcement installed and ready for concrete.

Concrete Mixture

The contractor used a VHES concrete containing a proprietary CSA-based cement binder and locally available aggregates. The mix was proportioned to achieve the minimum required opening-to-traffic flexural strength of 650 psi at opening. Concrete was mixed on-site using mobile (volumetric) mixers with electronic controls. The exact concrete mixture design properties and proportions were not available, but typical values for VHES mixture design properties and mixture proportions are summarized in Table B-6 and Table B-7, respectively.

Concrete Placement

Two mobile mixers simultaneously discharged concrete along one side of the repair area. Mobile mixer trucks slowly pulled forward and placed concrete to a height just above the adjacent slabs. Once both mobile mixers had discharged their concrete loads, a third mobile

Table B-6. Typical design properties of VHES concrete mixtures at SEA.

Property	Typical Value
Flexural strength (psi) at return-to-service for 100% payment	650
Slump (in.)	4.25
Air (%)	5.9
Unit weight (lb/ft^3)	142.8
w/cm ratio	0.45
Maximum aggregate size (in.)	1.5

mixer was used to fill the rest of the repair area, which required about ½ to ⅔ of its load. The first few cubic feet of concrete out of the mobile mixer were typically dry (lacked proper water proportion), which prompted the operators to make a judgment-based adjustment to the mix water. After slight adjustments, the concrete material became more fluid and consistent.

A roller screed was used to level and partially consolidate the concrete while a concrete vibrator was used to consolidate the concrete near the slab edges. The contractor ensured that the concrete was properly consolidated.

Finishing and Curing

A hand-tooled edge was formed adjacent to the existing portland cement concrete slabs. Afterward, a hand float was used to smooth and densify the concrete surface, and a broom finish was applied to provide surface texture. Approximately 10 to 15 minutes after finishing was completed and the surface had begun to set, water was manually sprayed on the concrete surface. This was followed by placement of a garden sprinkler to continuously apply water to the slab surface for an additional 30 minutes. An overview of the VHES concrete placement, finishing, and curing is shown in Figure B-12.

Material Testing

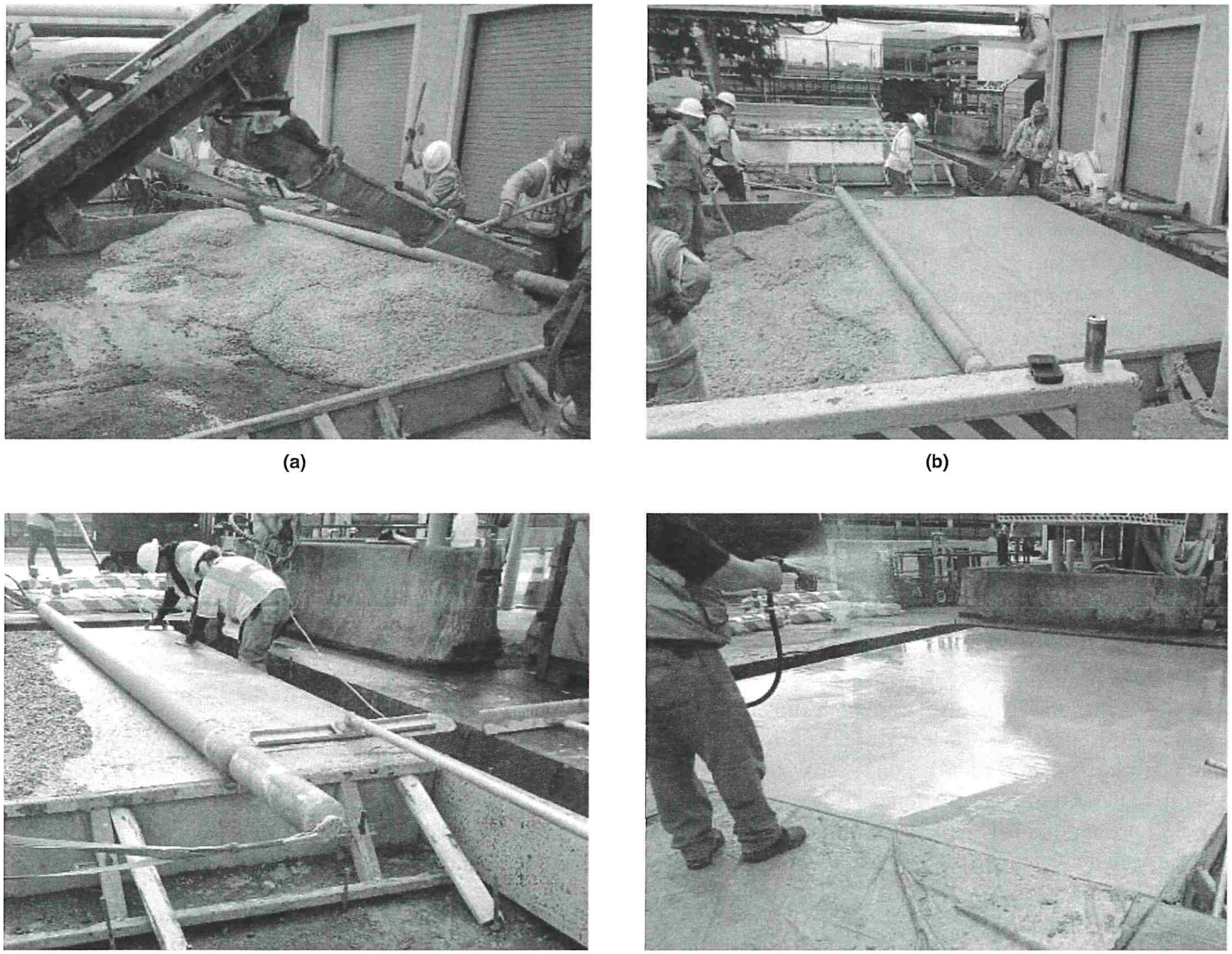
Several concrete beams were cast from the middle of the load from the second mobile mixer truck for each repair area. Beams were left to field-cure until approximately 30 minutes prior to

Table B-7. Typical proportions of VHES concrete mixtures at SEA.

		Proportion per yd^3	
Materials	ASTM	Weight (lb)	Volume (ft^3)
CSA cement	C1600	705	3.83
Coarse Aggregate No. 467	C33	1,799	10.80
Washed coarse sand	C33	1,092	6.62
Water		275	4.41
Air			1.35
Total			27.00

Note: Admixtures:

- Air entrainer at 2 ounces/hundredweight (oz/cwt)
- Water reducer at 4 oz/cwt
- Citric acid in solution at 1.4 oz/cwt
- Stabilizer at 0.3 oz/cwt
- Lithium nitrate solution at 9 oz/cwt



(a) (b)

(c) (d)

Source: Nichols Consulting Engineers, Chtd.

Figure B-12. Overview of VHES concrete placement at SEA: (a) initial concrete placement, (b) screeding of concrete, (c) finishing of concrete, and (d) initial (moisture) curing. The finishing process began immediately following the screeding.

the first strength test. Two beams were tested on the first repair slab at 3.5 hours with an average flexural strength of 850 psi, which greatly exceeded the flexural strength requirement of 650 psi at time of opening. The average 3.5-hour flexural strength for the second slab was 685 psi. The contractor was allowed some freedom in how quickly the VHES mixture reached opening strength. A contractor that can perform the demolition work quickly may opt for a slower-curing VHES concrete mixture; alternatively, a contractor that struggles with the demolition work may desire a faster-curing VHES concrete mixture to allow for more time for demolition.

Discussion

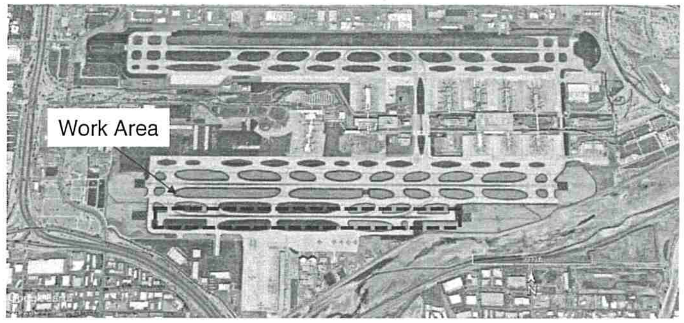
Observing the construction of three FDRs to replace cracked slabs in a commercial gate area provided several insights. Observations were supplemented by on-site discussions with the contractor and SEA personnel.

- **Advanced coordination with all stakeholders was paramount to successful delivery of rapid airfield slab repairs.** With this project occurring directly outside a gate, coordination with the airline was critical in securing a daytime closure that would not significantly impact the airline's operations. SEA inspectors were in constant communication with airline representatives once it was apparent the concrete would not be placed and cured before the end of the closure. The airline was able to secure a second daytime closure on the following day for FDR completion.
- **Safety and security required a significant commitment of airport personnel.** SEA operations vehicles continuously monitored and secured the work site. The work site was in a corner of the airport that received low traffic and SEA personnel made sure no nonconstruction vehicles or personnel entered the construction area.
- **Proper use of PPE was essential for both contractor and airport employees.** Excellent use of PPE, including vests, hard hats, gloves, eye and ear protection, boots, and respirators (when warranted), was noted on this project.
- **Protection of existing concrete during demolition was a challenge.** Slabs were saw cut into manageably sized pieces to minimize damage to adjacent concrete. Adjacent slabs were further protected by wood wedges installed into the saw cut joint to act as buffers from swaying concrete pieces as they were removed. Some minor damage still occurred to adjacent concrete.
- **Overall work-site cleanliness was important to minimize FOD.** The contractor laid plastic sheeting around the area to be replaced to keep the adjacent work area clean; this not only made cleanup easier but also minimized tracking of construction debris to locations outside the work area.
- **An initial volume of concrete produced by a mobile volumetric mixer should be discharged and disposed of off-site.** The first few cubic feet of concrete produced by the mobile mixing trucks was consistently dry and required judgment-based adjustment of mix water to obtain a workable concrete. After this adjustment, the concrete was consistent for the remainder of the discharge for that truck.
- **Upfront planning and preparation were important for placement of ESC.** Three mobile mixing trucks were required to produce enough concrete for each FDR: two mobile mixers working simultaneously produced most of the material required, while a third mobile mixer produced the remainder of the concrete necessary to fill the repair area. Continuous placement was necessary because of set times.
- **Being prepared for unexpected circumstances was an essential element of rapid FDR.** Removal of an unexpected reinforced concrete pipe cap delayed concrete placement until the following day. The contractor was able to backfill the repair areas with aggregate base and cover them with steel plates to allow the airline to use the gate between construction closures.
- **Awareness of the construction schedule (during construction itself) was very important.** Site-specific conditions (known or unknown) may slow the production rate and ultimately affect a contractor's ability to complete construction within the allotted time frame.
- **Attention to detail during construction was essential.** The contractor paid attention to many construction details, such as use of grout retention discs on dowel bars, wetting the base material prior to concrete placement, and verifying steel reinforcement depth.

In-Pavement Light Can Replacement, Full-Depth Repair, and Partial-Depth Repairs at Phoenix Sky Harbor International Airport

Project Overview

This project replaced in-pavement light can fixtures on the centerline of Runway 7R-25L that were settling below the pavement surface (considered to be an FDR). Additional work inside the runway safety area included preventive electrical maintenance, conversion to LED runway



Source: Google, n.d.

Figure B-13. Project location at Phoenix Sky Harbor International Airport.

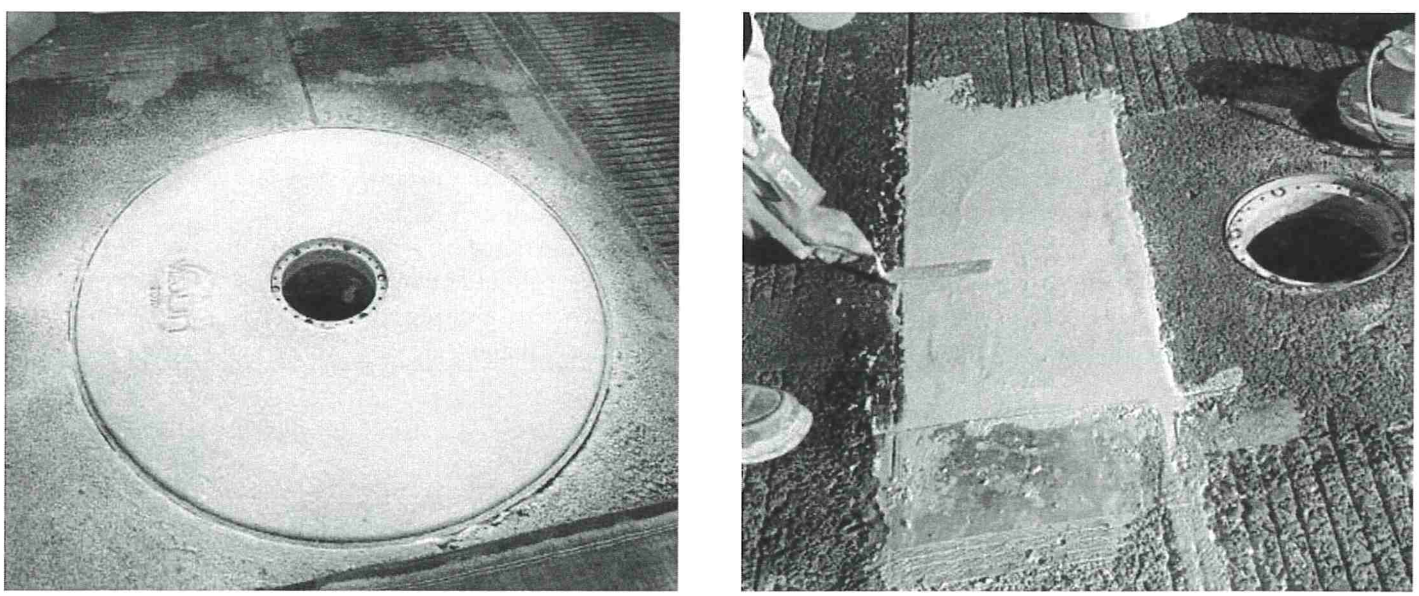
lighting, and repair and replacement of some runway electrical circuits. After many months of stakeholder communication and coordination, the runway was closed over a single weekend (from Friday 10:00 p.m. to Monday 7:00 a.m.). During the closure, the airport's maintenance crew took the opportunity to perform other maintenance activities, including removing tire rubber, striping, and completing PDRs on the runway pavement. Figure B-13 provides an overview of the project location, while Figure B-14 shows replacement of the light can and a PDR.

Table B-8 provides general information for this project.

Construction Observations for In-Pavement Light Replacement and Full-Depth Repair

Demolition

A 54-inch-diameter core bit was used to drill around the defective light can through the 24-inch-thick concrete pavement in advance of core removal. The core was removed by bolting



(a) (b)

Source: (a) Rummel Construction and (b) Nichols Consulting Engineers, Chtd.

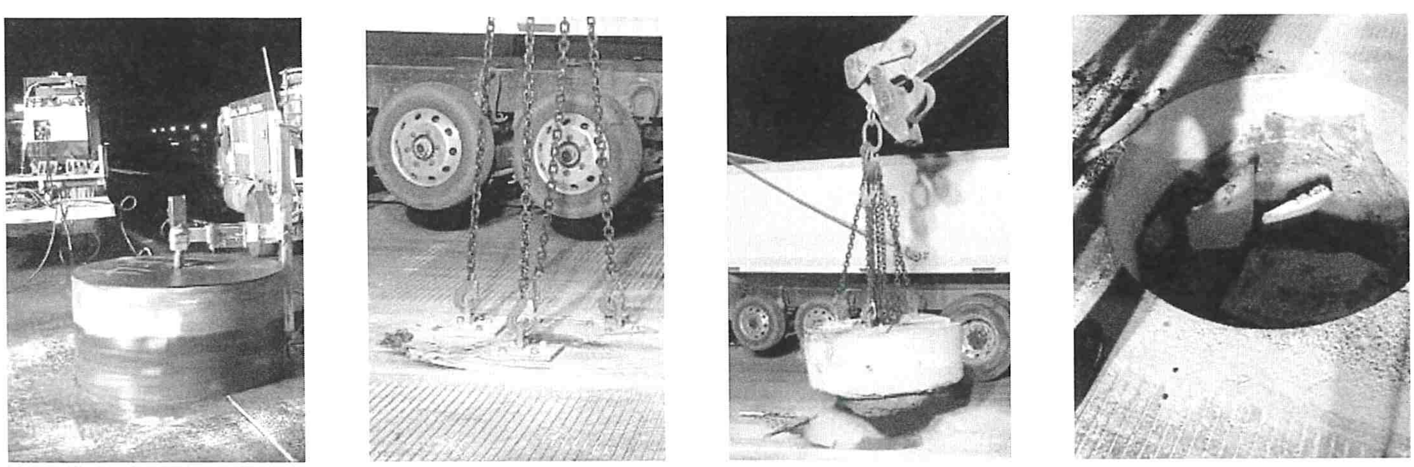
Figure B-14. In-pavement light can replacement at PHX: (a) FDR and (b) PDR.

Table B-8. General information: Project at Phoenix Sky Harbor International Airport.

Category	Detail
Airport location	Phoenix, Arizona
Owner	City of Phoenix
FAA classification	Large hub
FAA region	Western Pacific
LTPP climate region	Dry, nonfreeze
Facility and location of work	Runway 7R-25L
Closure time	Weekend (Friday 10:00 p.m. to Monday 7:00 a.m.)
Type of work	In-pavement light replacement, FDR, and PDRs
Dates of construction	November 1–4, 2019
Site visit weather conditions	Temperature: 54°F to 60°F Humidity: 20% to 30% Wind: 0–2 mph Clear sky
Work performed by	In-pavement light replacement and FDR: Contractor PDR: Airport personnel
Construction drawings and specifications?	In-pavement light replacement: Yes PDR: No
Emergency work?	No

four steel plates with rings to the concrete. Chains were hooked to the steel plate rings and to the arm of the backhoe, and the pavement core (with light can) was lifted out. Figure B-15 shows the removal sequence of the concrete core that contained the in-pavement light can.

According to the contractor, the main challenge was lifting out the core vertically to avoid causing damage to the adjacent concrete. A crane was used first but was not able to vertically remove the core. The contractor decided to use a backhoe and subsequently was able to remove the large core without damaging the existing concrete.



(a) (b) (c) (d)

Source: (a) Rummel Construction and (b–d) Nichols Consulting Engineers, Chtd.

Figure B-15. Removal sequence of in-pavement light can at PHX: (a) coring, (b) lift-pins installed, (c) lift-out, and (d) removal complete.

Table B-9. Design properties of PHX concrete mixture.

Property	Typical Value
Compressive strength (psi)	6,500
Specified slump (in.)	3–8
Design air (%)	1.5
Unit weight (lb/ft^3)	147.5
w/cm ratio	0.32

Preparation

After core removal, concrete pieces that had broken off the core were removed from the repair area. Electricians cleaned the electrical conduits that were filled with water and mud, and all excess water was removed from the repair area prior to installation of the new in-pavement light can fixture. An isolation joint was created with preformed joint compression material, and a reinforcing cage was installed around the light can. The light can was suspended from a beam flush on the pavement surface to set final elevation.

Concrete Mixture

The contractor used a 6,500 psi HES concrete with a nonchloride accelerator. The design properties and mix proportions of the concrete mixture are summarized in Table B-9 and Table B-10, respectively. The concrete mixture proportions were not adjusted for the volume of chemical admixtures.

Concrete Placement

A ready-mix truck delivered 4 cubic yards of concrete; only 2 cubic yards were placed in the FDR surrounding the new light can. The temperature of the concrete at the time of placement was 75°F with a slump of 6.75 inches. The concrete was consolidated with a mechanical vibrator.

Table B-10. Typical proportions of VHES concrete mixture at PHX.

		Proportion per yd^3	
Materials	ASTM	Weight (lb)	Volume (ft^3)
Fine aggregate	C33	1,093	6.69
Coarse aggregate	C33	1,750	10.61
Type II/V cement	C150	650	3.31
Class F fly ash	C618	215	1.58
Potable water	C1602	275	4.41
Air			0.41
Total			27.0

Note: Admixtures:

- ASTM C494 Type F High-Range Water Reducer at 66 oz/yd^3
- ASTM C494 Type A Water Reducer at 26 oz/yd^3
- ASTM C494 Type C Accelerator as requested

Finishing and Curing

Finishing was done by hand with a trowel. A spray-applied, wax-based curing compound was used for this work. After application of the curing compound, a wet burlap covering was placed on top to help cure the concrete surrounding the in-pavement light (Figure B-16).

Material Testing

The HES concrete was required to have a compressive strength of at least 6,000 psi at the time it was returned to service. This was not a concern, given the use of an HES concrete along with approximately 50 hours for curing before reopening the runway. The 24-hour, 48-hour, and 7-day average compressive strengths were 6,020, 7,440, and 8,140 psi, respectively.

Construction Observations for Partial-Depth Repairs

Demolition

The observed PDRs for this project were performed by using the chip-out method to expose and repair retrofitted electrical conduits that had collapsed and caused a short circuit. Figure B-17 shows an example of a marked area slated for PDR (over retrofitted electrical conduit) and the demolition and preparation process. First, the repair area was demolished by jackhammer to expose solid concrete. After concrete pieces were removed, a dry saw was used to saw cut a smooth edge around the repair boundary about 1.5 to 2 inches from the damaged area. A vacuum was used to remove dust and small pieces of concrete.

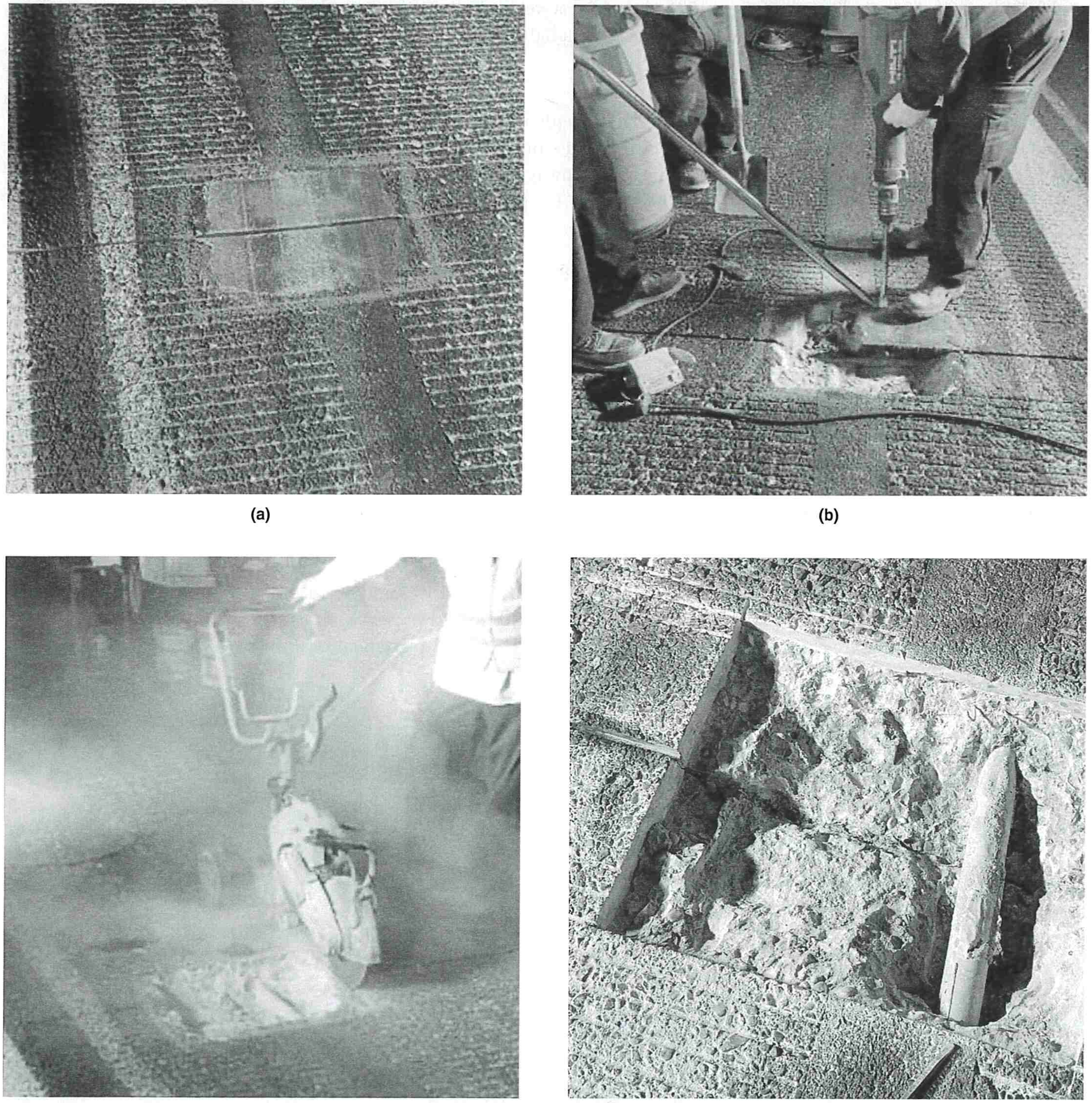
Preparation

The airport maintenance crew thoroughly cleaned the area of dust and debris and removed any moisture. Previous experience with this repair material indicated that the presence of dust, small aggregates, or moisture could cause early failure of the PDR. Prior to placement of the

(a) (b)

Source: (a) Rummel Construction; (b) Nichols Consulting Engineers, Chtd.

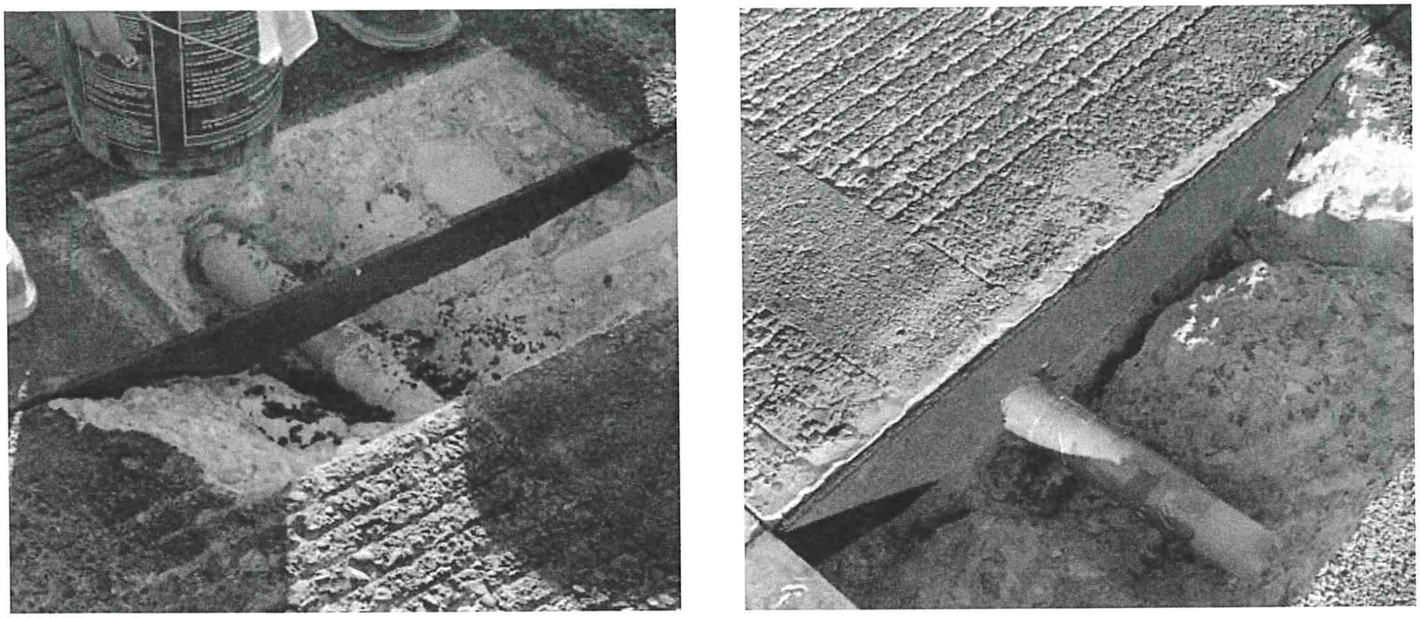
Figure B-16. FDR finishing and curing in-pavement light at PHX: (a) trowel finishing and (b) final curing with use of wet burlap. A wax-based curing compound was applied prior to the installation of the wet burlap covering.



(a) (b) (c) (d)

Note: Cleaning repair area with a vacuum is not shown.
Source: Nichols Consulting Engineers, Chtd.

Figure B-17. PDR demolition sequence at PHX: (a) area marked for PDR, (b) chip-out demolition method, (c) sawing a clean face, and (d) prepared area (exposed electrical conduit).



(a) (b)

Source: Nichols Consulting Engineers, Chtd.

Figure B-18. Preformed joint compression material used at PHX to reestablish transverse joints.

repair material, the existing transverse joint was reestablished with preformed joint compression material (Figure B-18).

Materials and Installation

The PDR repair material used for this project was a proprietary, two-component polymer concrete that uses fine aggregate as an extender. During cold weather, the airport adds an accelerator by the same manufacturer. The airport also adds a small portion of aggregate, as it believes the aggregate improves durability.

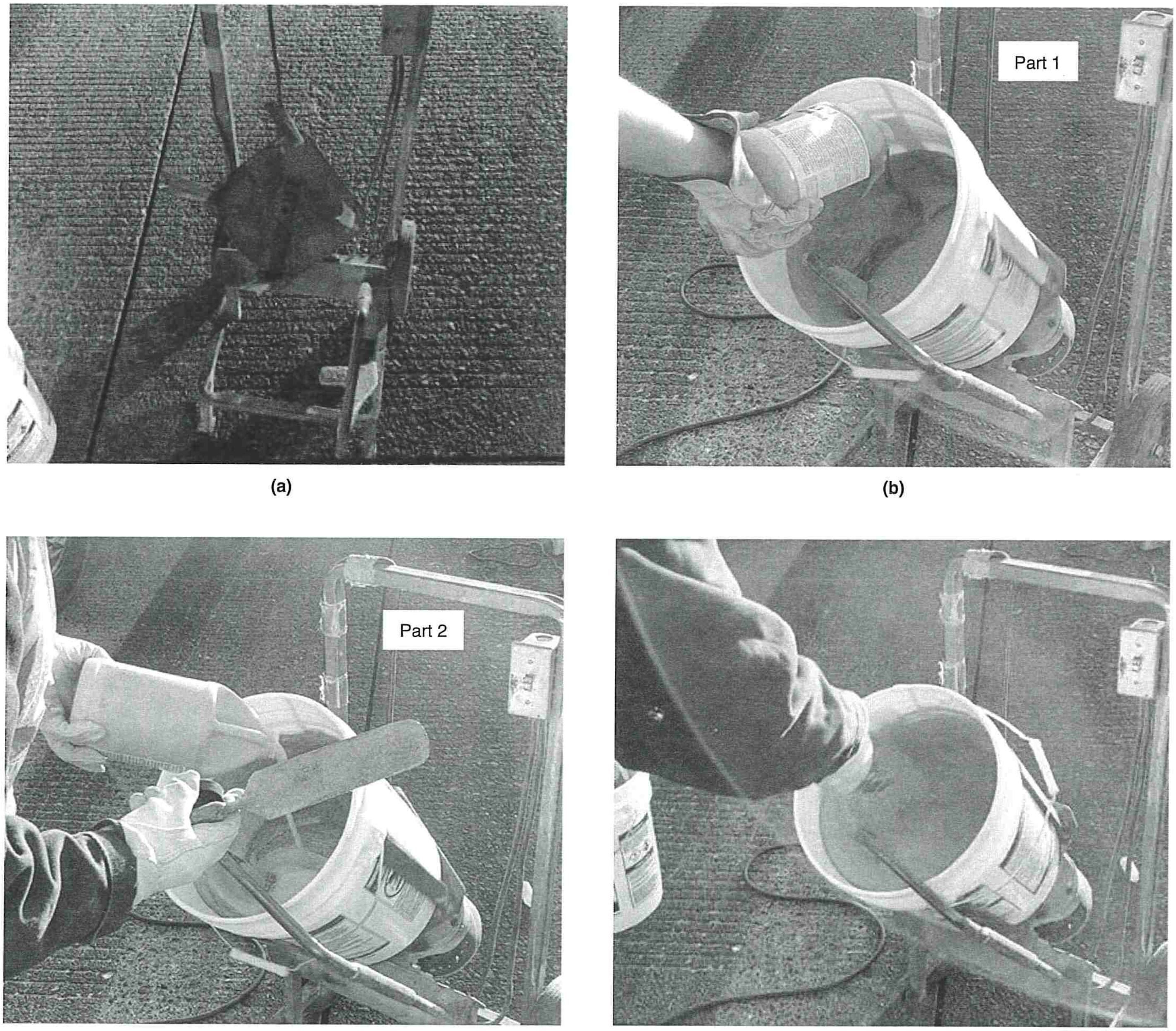
Mixing was done according to the product manufacturer's instructions with a rotating bucket mixer with a paddle inserted to blend the material. The process began with a 5-gallon bucket of fine aggregate and ended after the addition of both parts of the binder material and mixing for a specified amount of time. Figure B-19 depicts the polymer concrete mixing process for the selected product.

The PDR material appeared to be consistent and flowable when poured from the 5-gallon buckets into the clean repair area (Figure B-20). The material remained workable while it was hand troweled to finished grade and did not set up too quickly. Consolidation was not required for this type of self-leveling PDR material, nor was curing required for this polymer concrete material; the set time was approximately 15 minutes after mixing.

Discussion

Observing PDR and FDR construction for replacement of in-pavement light provided the following insights. These observations were supplemented by on-site discussions with the contractor and airport personnel and by follow-up correspondence.

- **Advanced coordination with all stakeholders was paramount to successful delivery of rapid airfield slab repairs.** The stakeholder planning for this project started in April 2019,



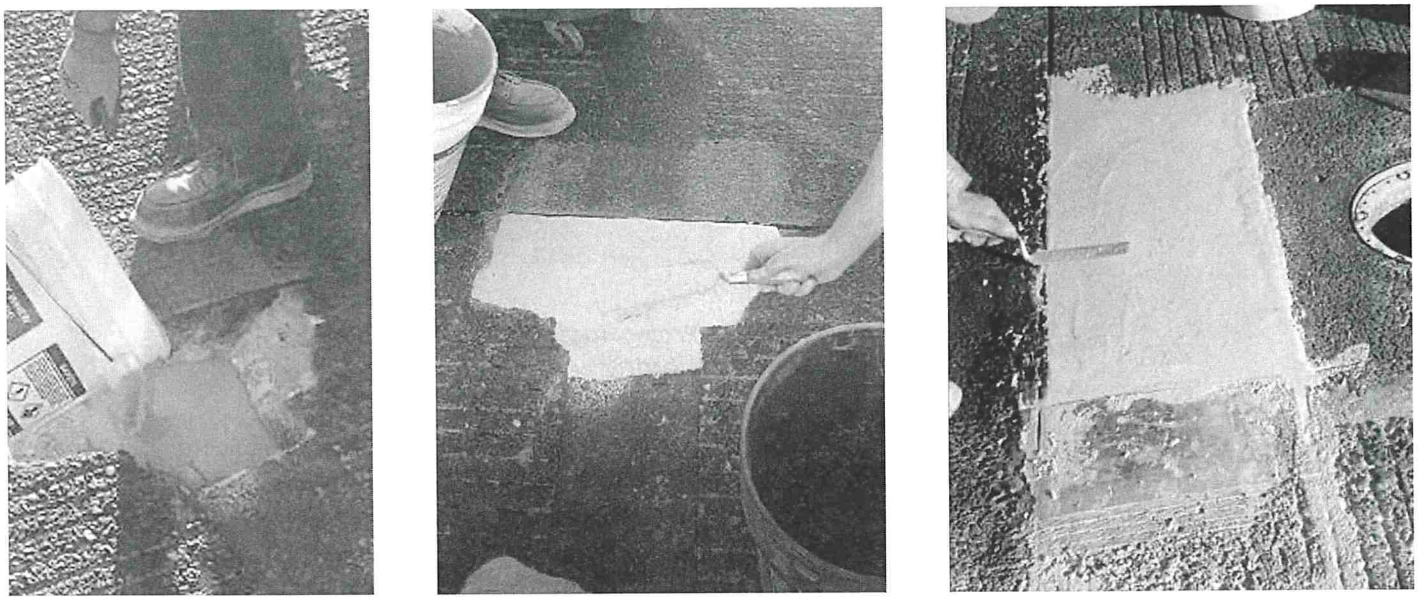
(a) (b) (c) (d)

Source: Nichols Consulting Engineers, Chtd.

Figure B-19. Mixing process for polymer concrete used at PHX for PDR: (a) electric mixer, (b) binder (Part 1) added to aggregate, (c) binder (Part 2) added, and (d) mixing.

approximately 7 months prior to the start of construction. Some of the critical components that made this project a success were good communication and coordination with stakeholders to schedule and carry out the runway closure. This allowed project work to be carried out prior to the busy holiday season.

- **Safety and security required a significant commitment of airport personnel.** Barricades were placed in all working areas and on the closed taxiway intersections. To improve safety and security, airport operations vehicles continuously secured all work areas. The contractor and airport coordinated in advance so that plenty of airport operations personnel were on-site to provide escort for construction activities.



(a) (b) (c)

Source: Nichols Consulting Engineers, Chtd.

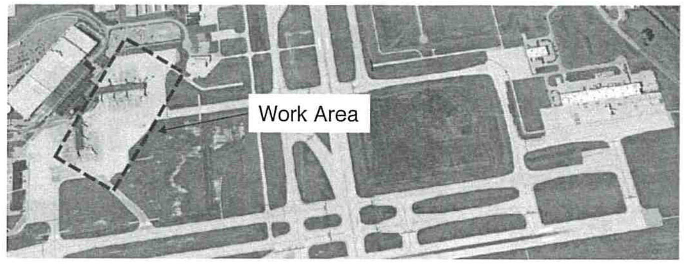
Figure B-20. Material installation at PHX for PDR: (a) placement, (b) spreading, and (c) leveling.

- **Proper use of PPE was essential for both contractor and airport employees.** Use of respirator equipment was especially important during drilling and cleaning of holes for dowel bars.
- **A major challenge during the planning phase was approval of the concrete and additives to be used for the concrete mix.** The FDR concrete mix was delivered on time and met the specifications for consistency and compressive strength. Since the air temperature was in the low 50s (°F), a nonchloride accelerator admixture was used in the concrete mixture.
- **The local experience of airport maintenance crews played an important role in the longevity of PDRs.** Airport maintenance crews understood that the presence of any moisture, dust, or debris on the concrete surface that was prepared for repair could cause premature failure of the repair. The crews paid close attention to cleaning and drying the repair area prior to placement of the repair material.
- **Being prepared for unexpected circumstances was an essential element of rapid slab repair.** A crane was not able to vertically lift the concrete core (containing the in-pavement light can) without risking damage to the adjacent concrete. The contractor quickly adjusted its approach and used a backhoe to successfully remove the concrete core.
- **Awareness of the actual PDR completion rate compared with closure time was very important.** Demolition for the PDRs took longer than anticipated, since the previously placed repair material was in sound condition. The crews had to be careful not to demolish more repair areas than could be completed (repair material placed and cured) prior to the end of the scheduled closure.

Partial-Depth Repair at Gerald R. Ford International Airport

Project Overview

As part of a larger apron expansion project at Gerald R. Ford International Airport (GRR), PDRs were performed on the passenger terminal apron to repair spalls. The spalls resulted from winter snowplowing operations and improper edge finishing during concrete placement.



Source: Google, n.d.

Figure B-21. Project locations at Gerald R. Ford International Airport.

PDR work was carried out during multiple daytime work shifts. Partial or full apron closures were not utilized, mainly because of the reduction in aircraft traffic resulting from the COVID-19 pandemic. Stakeholder coordination allowed daytime construction in specified areas during periods with no (or minimal) aircraft operations on the terminal apron. Figure B-21 provides an overview of the project location, and Table B-11 provides general project information.

Construction Observations

Demolition and Preparation

The contractor and project engineer walked every concrete joint within the project limits and marked locations for PDRs. If a spall was less than 1 inch from the face of joint, loose concrete material was removed for joint resealing. If the spalled area exceeded the 1-inch criterion, it was treated as a PDR. In this case, the contractor saw cut a rectangular area that extended 1 inch past the limits of the spalled (or potential spall) area. The material inside the boundaries was removed by making several overlapping saw cuts with a wide-blade concrete saw to a depth of 2 to 3 inches. The repair area was thoroughly cleaned and dried with compressed air prior to

Table B-11. General information: Project at Gerald R. Ford International Airport.

Category	Detail
Airport location	Grand Rapids, Michigan
Owner	Gerald R. Ford International Airport
FAA classification	Small hub
FAA region	Great Lakes
LTPP climate region	Wet, freeze
Facility and location of work	Terminal apron
Closure time	Daytime (hours varied)
Type of work	PDR
Dates of construction	Various (site visit on July 21, 2020)
Site visit weather conditions	Temperature: 72°F Humidity: 56% Wind: 5 mph Partly cloudy
Work performed by	PDR: contractor
Construction drawings and specifications?	PDR: Yes
Emergency work?	No

placement of the PDR material. Previous experience indicated that cleaning and preparation were important to the quality of PDR. Figure B-22 shows the demolition sequence.

The contractor watched the daily flight schedule via the GRR airport mobile app and coordinated PDR work with airport operations staff. PDRs were completed between peak flight times, and the contractor had a spotter watching for aircraft operating on the apron.

Materials and Installation

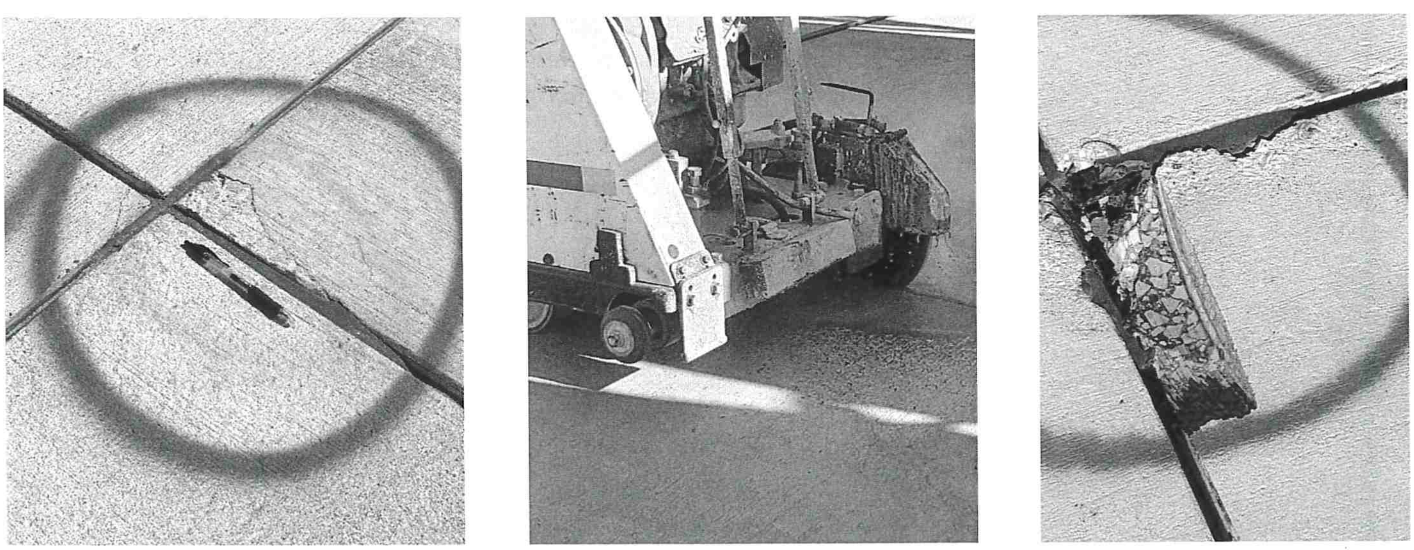
The PDR repair material used for this project was a two-component, epoxy-based elastomeric concrete that uses fine aggregate as an extender. Mixing was done according to manufacturer instructions with a paddle attachment affixed to an electric drill. Two binder components were measured, added to a 5-gallon bucket, and blended. Fine aggregate was added to the blended binder and mixed again. Figure B-23 shows the elastomeric concrete mixing process for the selected product.

The PDR material was manually poured from the 5-gallon buckets into the clean repair area (Figure B-24). According to the contractor, the material remained workable while it was hand-troweled to a finish grade and did not set up too quickly. Consolidation was not required for this type of self-leveling PDR material, nor was curing required for this elastomeric material. The joint was reestablished by dry sawing (hand grinder) the hardened repair material, followed by cleaning and resealing of the joint. The PDR was returned to service within 2 hours. Figure B-25 shows a completed PDR with sealed joints.

Discussion

Visiting a PDR construction site at GRR provided the following insights. These observations were supplemented by on-site discussions with the contractor, project engineer, and airport personnel, along with follow-up correspondence.

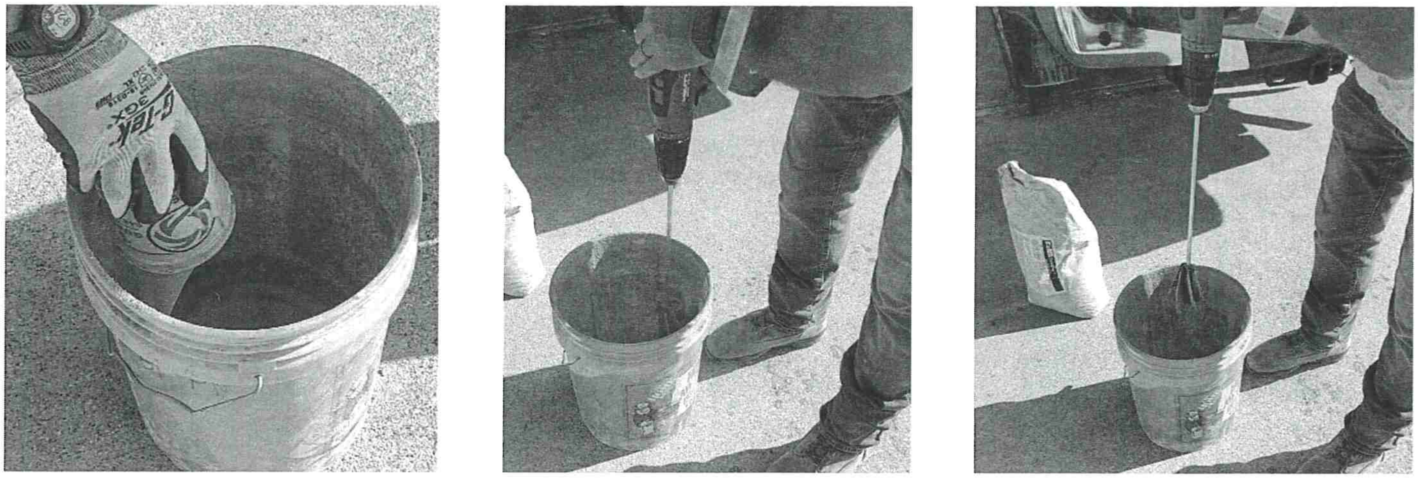
- This airport has an aggressive approach to maintaining airfield concrete pavements. Approximately $500,000 is spent annually for PDR and FDR.



(a) (b) (c)

Source: (a) Nichols Consulting Engineers, Chtd. and (b and c) Ajax.

Figure B-22. PDR demolition sequence at GRR: (a) marked location of PDR, (b) sawing, and (c) area prepared for PDR.



(a) (b) (c)

Source: Ajax.

Figure B-23. Mixing process for elastomeric concrete used at GRR for PDR: (a) add binder components, (b) mix binder, and (c) add aggregate and mix.

- **Coordination with all stakeholders was paramount to successful delivery of rapid airfield PDRs.** The contractor monitored the daily flight schedules and coordinated work locations and timing with airport operations. This allowed daytime PDRs during periods with no (or minimal) aircraft traffic.
- **Closures were not needed, owing to proper planning and coordination with stakeholders.** The contractor worked when aircraft were not at the gates or using the apron, and repairs were opened to traffic within 2 hours of material placement.
- **The contractor's attitude toward quality work and implementation of quality control was very important.** The contractor believed that attention to detail during construction results in longer-lasting PDRs. The contractor performed follow-up inspections of concrete slabs in the work areas and re-marked spalls that were missed during construction and PDRs that needed to be corrected.
- **Monitoring weather was important because the area is in a rainy climate.** The contractor monitored the weather forecast and did not start PDRs if rain was imminent.

(a) (b) (c)

Note: The joint was reestablished and resealed following the specified material curing time.
Source: Ajax.

Figure B-24. Installation sequence at GRR for PDR material: (a) place material, (b) level material, and (c) self-consolidation.

Source: Nichols Consulting Engineers, Chtd.

Figure B-25. Example of completed PDR with sealed joint at GRR.

Full-Depth and Partial-Depth Repairs at Cincinnati/Northern Kentucky International Airport

Project Overview

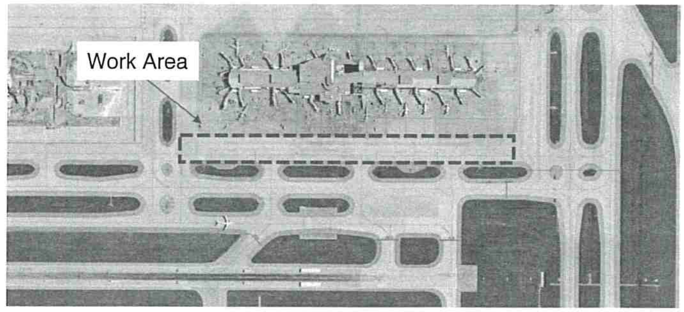
As part of a multiyear repair project at Cincinnati/Northern Kentucky International Airport (CVG), deteriorated concrete slabs associated with Runway 9/27 and Taxiways K and J were identified for repairs. Cracking and spalling were the major drivers triggering the need for PDR and FDR. Typical slabs are 25 by 25 feet by 18 inches thick.

The first portion of work was performed on the taxilane along the Concourse B apron (Ramp 3). The Ramp 3 taxilane work was originally planned for nighttime closures, but with reduced operations as a result of the impact of COVID-19, the airline using the apron was able to relocate gate operations, and the work was completed over an extended closure. Future phases of repair work are anticipated to be on an accelerated schedule. Although this phase was not accelerated, there are still lessons to be learned. Figure B-26 provides an overview of the project location, while Table B-12 provides general information for this project.

Construction Observations for Full-Depth Repair

Demolition

First, the slab perimeter was cut, and then the slabs were further cut into approximately 16 pieces prior to slab removal. The contractor indicated that interior saw cuts are often performed at a slight angle to facilitate removal of the first piece. Removal was done by installing lift anchors into holes drilled into one piece that was then lifted out with an excavator. Subsequent pieces were removed with an excavator. Figure B-27 provides images of the slab removal process. Wood wedges were driven into the saw cut joint around the slab to help prevent damage to adjacent concrete during the removal process.



Source: Google, n.d.

Figure B-26. Taxilane project location at Cincinnati/Northern Kentucky International Airport.

Preparation

During slab removal, some of the stabilized base was bonded to the underside of the slab and left a portion of the base damaged. Any areas of base damage were replaced with concrete after slab removal (the existing base was lean concrete or asphalt).

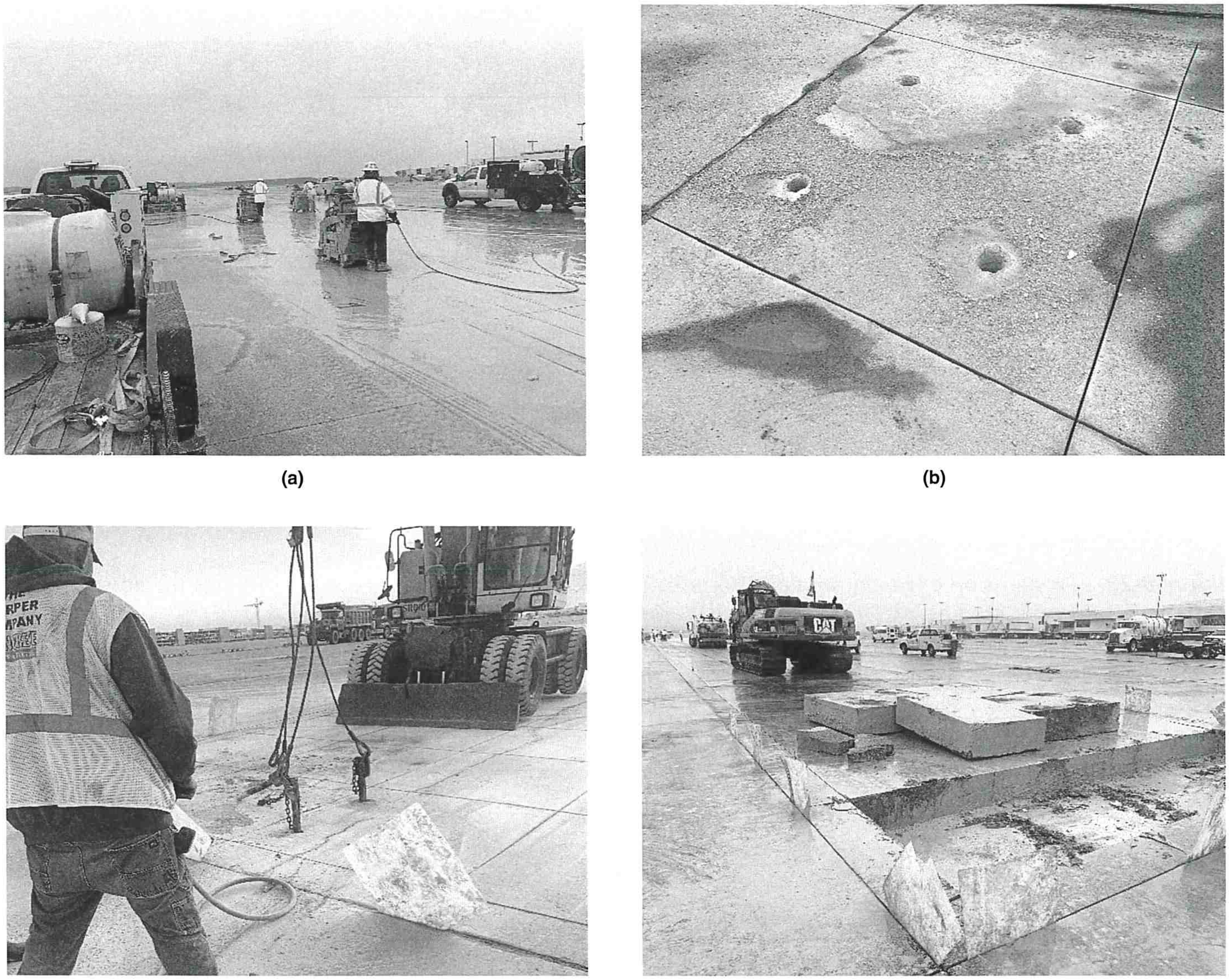
Dowel bars were installed along the entire perimeter of the repair areas. Holes were drilled into the existing slabs with a 4-gang pneumatic dowel drill. Epoxy was injected into the drilled holes and dowel bars were inserted. Retention discs were installed over each dowel bar (and against the slab) to prevent the epoxy from seeping out. Dowel bar baskets were anchored at interior transverse joint locations for consecutive slab replacements. A double application of curing compound was applied to the stabilized base as a bond breaker. Sequential preparation of a repair area for concrete placement is shown in Figure B-28.

Concrete Mixture

The contractor used a conventional concrete and locally available aggregates. The mix was proportioned to achieve the minimum required opening-to-traffic flexural strength of 650 psi at

Table B-12. General information: Project at Cincinnati/Northern Kentucky International Airport.

Category	Detail
Airport location	Hebron, Kentucky
Owner	Kenton County Airport Board
FAA classification	Medium hub
FAA region	Southern
LTPP climate region	Wet, freeze
Facility and location of work	Apron taxilane at commercial gates
Closure time	Daytime
Type of work	PDR and FDR
Dates of construction	September 22 through December 10, 2020 (Ramp 3); observed on October 26, 2020
Site visit weather conditions	Temperature: 47°F to 51°F Humidity: 77% to 93% Wind: 0–12 mph Cloudy sky
Work performed by	Contractor
Construction drawings and specifications?	Yes
Emergency work?	No



(a) (b)

(c) (d)

Note: Shims installed at slab edges to prevent damage to adjacent slabs.
Source: C&S Engineers, Inc.

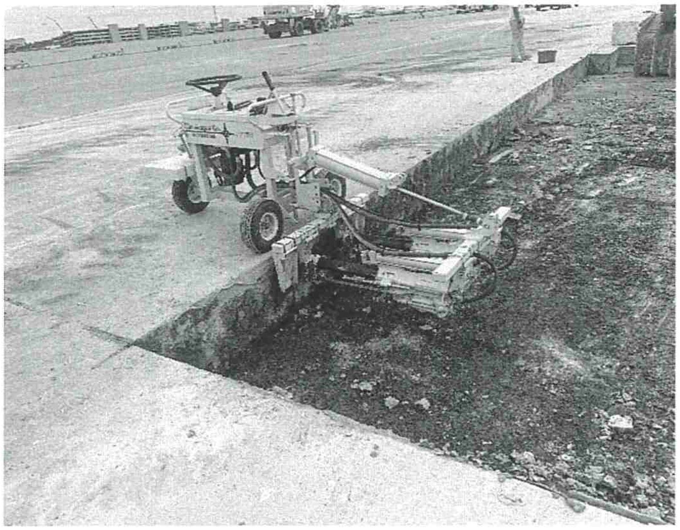
Figure B-27. Removal sequence of existing cracked slab at CVG: (a) sawing slabs into smaller pieces, (b) lift-pin holes drilled into slab pieces, (c) lift-pins installed, and (d) slab pieces removed.

28 days. Concrete was mixed adjacent to the airfield with the use of a batch plant and delivered to the work site by nonagitated dump trucks. Typical values for mixture design properties and mixture proportions are summarized in Table B-13 and Table B-14, respectively.

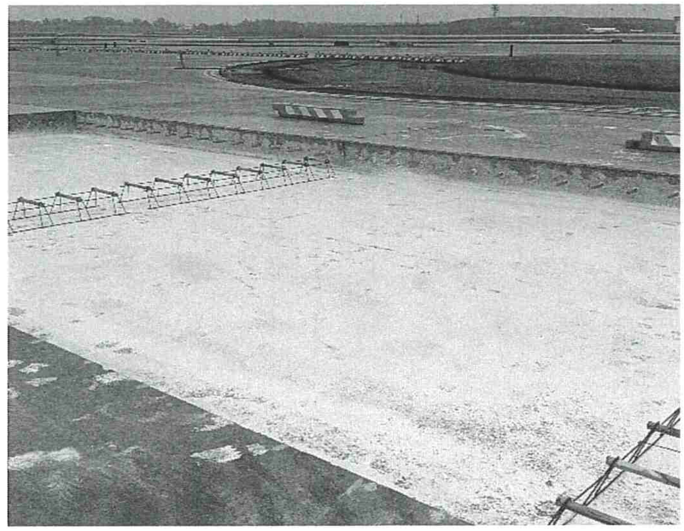
Air content and slump tests were conducted from random loads in determined sublots. Flexural strength beams were also produced for later testing.

Concrete Placement

As mentioned previously, the concrete mixture was mixed at an adjacent batch plant and delivered to the work site in nonagitated dump trucks. To facilitate placement, a material transfer vehicle was used to place the concrete. Consolidation was performed with internal (or spud) vibrators. A roller screed was used to level the concrete surface and establish final grade. Figure B-29 illustrates the procedure for FDR concrete placement.



(a)



(b)

Source: (a) C&S Engineers, Inc., and (b) Applied Pavement Technology, Inc.

Figure B-28. Preparation of repair area at CVG prior to concrete placement: (a) drilling of holes for dowel bars and (b) curing compound applied as bond breaker and dowel bars installed.

Table B-13. Typical design properties of CVG concrete mixture.

Property	Typical Value
Flexural strength (psi) at 28 days for 100% payment	650
Slump (in.)	4 max.[a]
Air (%)	5.5
w/cm ratio	0.38–0.45
Maximum aggregate size (in.)	1.5

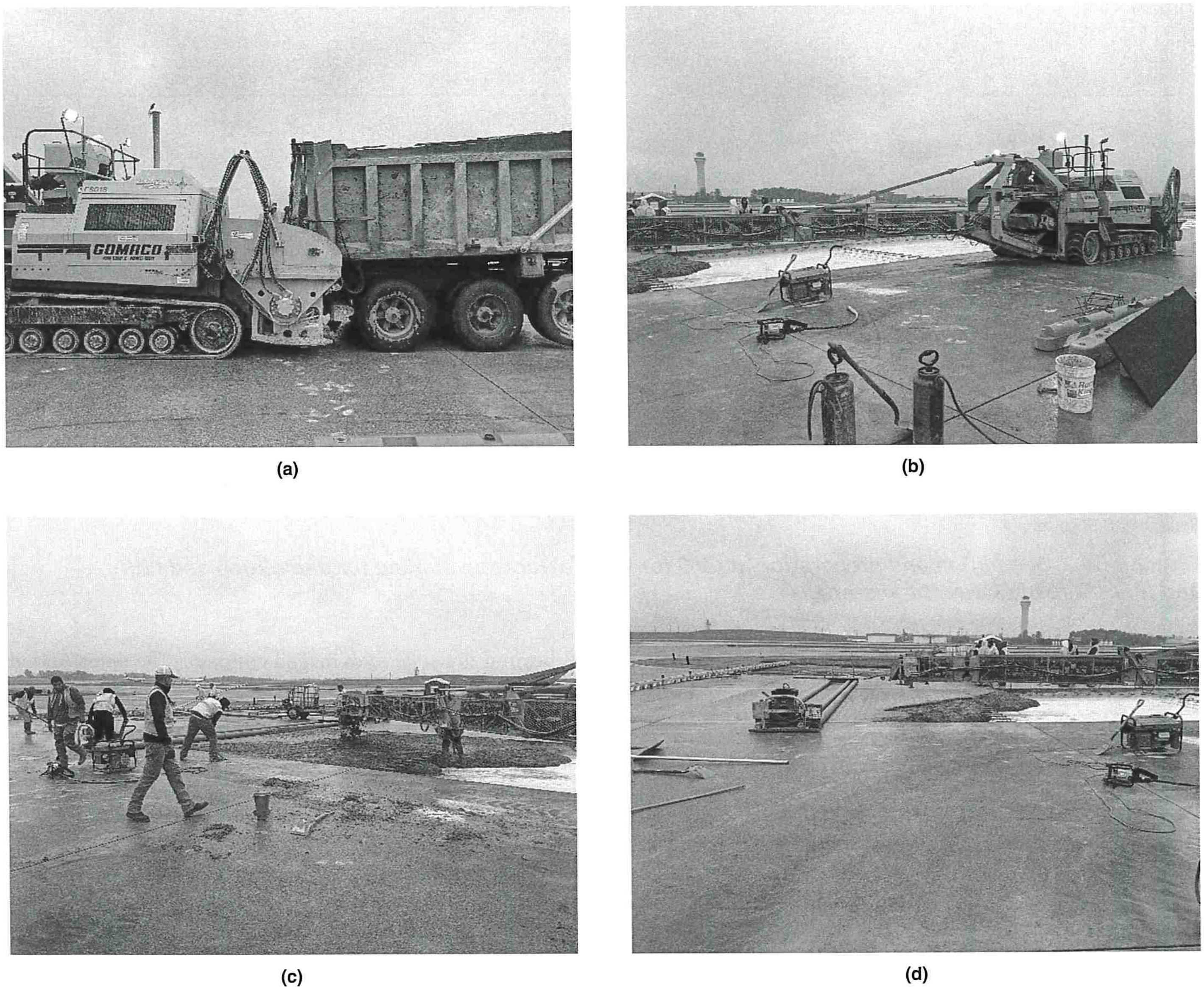
[a]For hand placement.

Table B-14. Typical proportions of CVG concrete mixture.

		Proportion per yd^3	
Materials	**ASTM**	**Weight (lb)**	**Volume (ft^3)**
Type I/II cement	C150	282	1.43
Slag cement	C989	282	1.59
Coarse Aggregate No. 57	C33	1,552	9.29
Coarse Aggregate No. 8	C33	221	1.34
Natural sand	C33	1,380	8.34
Water		220	3.53
Air content			1.49
Total			27.0

Note: Admixtures:

- ASTM C260 Air-Entraining Admixture at 1.3 oz/cwt
- ASTM C494 Water Reducer at 3 oz/cwt



Source: Applied Pavement Technology, Inc.

Figure B-29. Overview of FDR concrete placement at CVG: (a) loading concrete into a belt placer, (b) placing concrete, (c) consolidating concrete, and (d) screeding concrete.

Finishing and Curing

A bull float and edging tools followed the roller screed. Surface texture was applied by a broom finish. A white-pigmented curing compound was applied after finishing was completed.

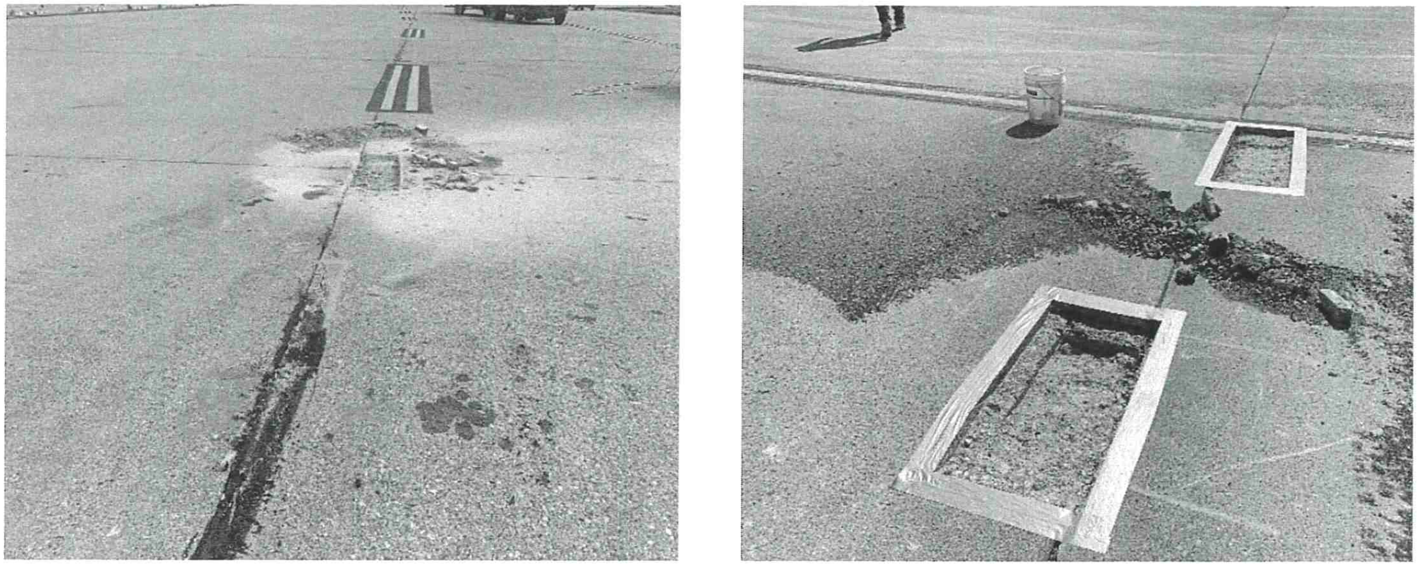
Joints

Interior transverse joints were saw cut to a depth of ⅓ the slab thickness. Joints were then widened to 0.5 inch at the surface to create the joint sealant reservoir and beveled.

Construction Observations for Partial-Depth Repair

Demolition and Preparation

Figure B-30 shows an example of a marked area slated for PDR and the demolition and preparation process. The perimeter of the repair area was saw cut (minimum depth of



(a) (b)

Source: C&S Engineers, Inc.

Figure B-30. Demolition and preparation at CVG for PDR: (a) location marked for demolition and PDR and (b) area ready for repair material.

2.5 inches) approximately 2 inches beyond the edge of damaged concrete. The deteriorated material was removed with a jackhammer to expose sound concrete, and the repair area was thoroughly cleaned to remove dust and small pieces of concrete after removal of the larger pieces.

Materials and Installation

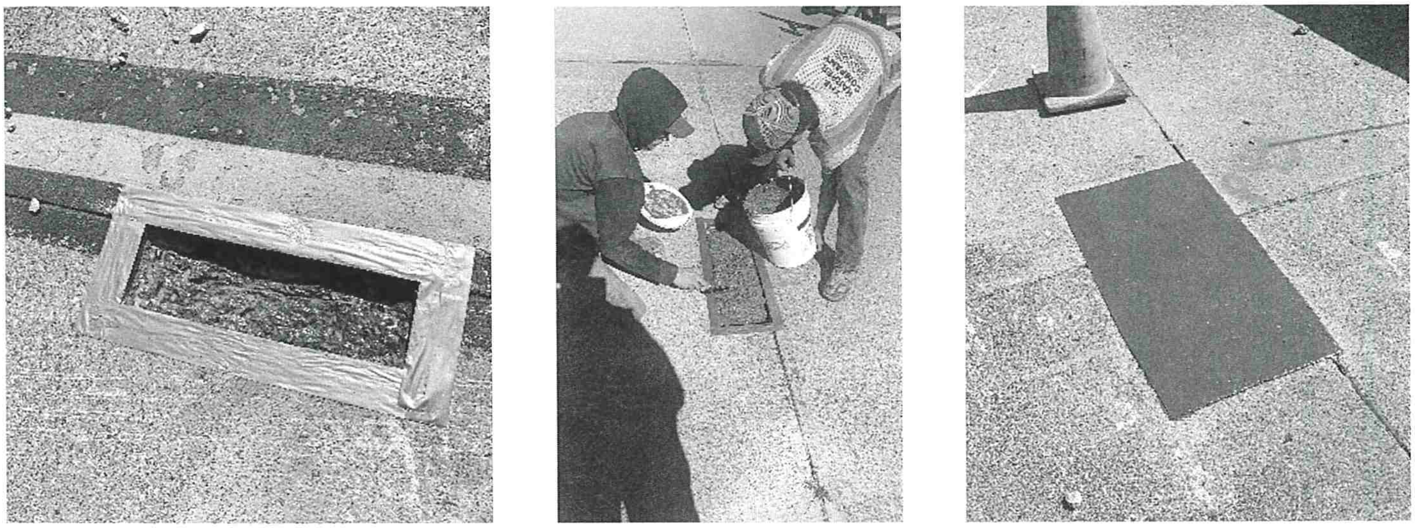
The PDR repair material used for this project was a three-component (A + B + C), epoxy-based elastomeric concrete consisting of elastomeric activator and patch (A + B) and aggregate (C). Mixing was done manually and in accordance with product manufacturer instructions. The two binder components were added to the 5-gallon bucket of aggregate and blended.

A two-component (A + B) bonding agent was applied to the surface of the repair area immediately prior to placement of PDR material. The PDR material was manually poured from the 5-gallon buckets into the clean repair area (Figure B-31). The surface of the repair was then trowel finished. Consolidation was not required for this type of self-leveling PDR material, nor was curing required for this elastomeric material. The joint reservoir and sealant were reestablished after the material hardened.

Discussion

The following observations were made, supplemented by on-site discussions with the contractor and project engineer:

- **Coordination with all stakeholders was paramount to successful delivery of rapid airfield PDRs.** Although this project was initially planned as nighttime work, coordination with stakeholders (regarding COVID-19 reduction in aircraft operations) allowed the first phase of work to be performed during an extended daytime closure. An extended closure allowed for a less time-sensitive environment in which to demonstrate techniques and materials that will be used in future phases.
- **Safety and security required a significant commitment of airport and contractor personnel.** Barricades were placed in all working areas to prevent airfield traffic from entering work



(a) (b) (c)

Source: C&S Engineers, Inc.

Figure B-31. Installation of PDR material at CVG: (a) area prepared for repair material, (b) placement of repair material, and (c) finished PDR.

zones and construction traffic from entering active airfield facilities. As part of the project requirements for safety and security, the contractor hired airport staff (off-duty police, fire, and maintenance personnel familiar with the airfield) to continuously monitor all work areas. The contractor also staffed a dedicated security gate and provided escort for construction activities.

- **Local experience with repair materials played an important role in the longevity of PDRs.** The airport and contractor both had experience with the PDR material and understood the requirements for preparation, placement, and curing.
- **Repair plans needed to be well-defined.** As work progressed, the quantity of PDR increased significantly from initial plan quantities, which required assessing the available budget and repair types.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GHSA	Governors Highway Safety Association
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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